February 1947

Development of

Ford Tank Engines

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Not bad; will trim much of the testing/analysis reporting.

Note last rel item from ASME journal. Get copyrights?

RECORD OF
ARMY ORDNANCE RESEARCH AND DEVELOPMENT
IN WORLD WAR II

History of Development of
Ford Tank Engines

brief but balanced..
~~With [illegible]~~

History of Development of Ford Engines

By 1939 it had become apparent that this country would be required to supply in great numbers larger and more efficient engines for powering larger and faster aircraft along with tanks, trucks, jeeps, guns, and ammunition.

The management of the Ford Motor Co. felt that there existed a definite need for an aircraft engine which conceded no advantage to increased displacement as a means for obtaining greater horse-power as at the time proposed by many engineers in this country and abroad. The company's design and development program was initiated for the main purpose of increasing specific output with a nominal-displacement engine size.

An upright 60-deg, V-12 liquid-cooled engine with a displacement of 1650 cu. in. was selected because of past experience with the Liberty and the Rolls Royce engines. All available fuel, metallurgical, and tool resources were considered. It was paramount that the end be achieved from a high-output viewpoint, both in horsepower and quantity of production.

Design studies began July, 1940, from which it was decided to produce a model composed of only two of the twelve cylinders, for the sole purpose of conducting the preliminary engine testing. The rear two cylinders were used, thus approaching the twelve-cylinder operation with identical camshaft and accessory drives, bearings, rods, pistons, piston rings, and oiling system, all of which could be readily tested and checked with this arrangement.

Engine Development Program

Three months after the beginning of necessary design and drafting layout, the first engine was built and assembled, ready for testing on November 15, 1940. The first tests, as is usual, served to iron out design wrinkles such as bearing materials, oiling of cams and cam followers, and scuffing of pistons and piston rings. Considerable work was done to establish combustion-chamber design and engine timing, in an over-all effort to obtain peak performance.

Within 3 months the output was raised from 115 bhp to approximately 150 bhp at 3600 rpm as a sea-level engine without supercharging. This gave a 0.545-bhp per cu in. displacement, which was a fine starting point for superchanging. These developments and improvements were solved much more easily and quickly than if they had used a multicylinder engine.

The building of the multicylinder engine, referred to as the "A" design, followed immediately with a finished engine, mounted on a test stand and ready for testing in the early part of August, or 9 months later.

The Ordnance Department, having heard of the gratifying results obtained on the two-cylinder model, became interested in view of the urgent requirement for a high-output engine to propel the 25 to 30-ton medium tank.

The company was approached with a proposal to develop a power plant that could be installed and harnessed in the current-production medium tank, at that time powered by the R975 radial air-cooled Continental Aircraft engine.

Hurriedly surveying the existing medium-tank engine compartment, Ford engineers suggested that by cutting the length, that is, using 8 of the 12 cylinders of the already designed and partially developed aircraft engine, it would be possible to produce within a reasonably short length of time, an engine that would meet the necessary power-plant requirement, and that would fit the existing hull with only a few slight alterations.

Medium and heavy tanks, it was learned through 4 years of experience, are required to perform with a great degree of maneuverability across country, pulling from 2 per cent to 80 per cent of the weight of the vehicle, thus making it essential that the engine be flexible and quick in response to the driver's foot acceleration. Its power output must easily be controllable and it should have good pulling power at low revolutions; in other words, a "buffalo-type" engine.

The characteristics of the engine should be such that frequent gear changes can be dispensed with as far as possible. It should have a wide speed range. The cooling system must function satisfactorily under extreme climatic conditions, independently of the speed of the vehicle. The rate of cooling should be easily adjustable to suit variations in atmospheric temperatures. The engine should be extremely economical in order to give the tank the maximum possible radius of action. Maximum reliability, minimum need for care and maintenance, and easy accessibility to parts which have to be serviced or changed are essential. All inaccessible parts should have a life of at least 600 hr (a tank averages approximately 10 mph.). Finally, the most important requirement is that the space occupied by the complete power unit, including cooling system, fuel tank, air cleaners, etc., should be kept down to an absolute minimum.

In the absence of this valuable knowledge, which the Ford Co. ultimately acquired the hard way, they proceeded on September 15, 1941, with the design, layouts, and details of a proposed engine that was manufactured, assembled, and placed on the test stand by January 14, 1942, within a period of 5 months.

The engine, a 60-deg V-type eight-cylinder four-cycle with valve in head, was liquid-cooled using an 80-octane gasoline as fuel. It was designed in five individual major assemblies, as follows: The cylinder block and crankshaft, with pistons and connecting rods; the cylinder heads, accessory drives, end cover, and oil-pan assemblies, . The five assemblies were treated as units and so arranged that they could be easily handled and were easy to replace in the theater of battle.

Details of Eight-Cylinder Engine

The cylinder block and crankcase, made of aluminum, were cast in one piece to aid in obtaining structural rigidity. This has been a Ford practice and experience comfirms its merit. The high loads and internal stresses developed by the engine can be handled better without undue distortion, in this en bloc arrangement. The cylinders are surrounded by a full-length water jacket and are lined with an oil-hardened steel dry-type sleeve, finished and honed in place. The parting line of the crankcase was on the center line of the crankshaft supported by five main bearings. The five main-bearing caps were of permanent-mold aluminum die-cast, designed with a heavy beam section and supported by a forged-steel channel between the studs, through the cap, and tapped directly into the aluminum crankcase.

The crankshaft, a one-piece nitrided steel casting, with integral counterweighting, was a product of design and development to which was contributed all of the metallurgical experience and engineering resources of the author's company.

The piston was a cast-aluminum design, the length of which is almost equal to the diameter, being somewhat greater than the length of the average aircraft piston. The increased piston stabilization, which resulted from this better length-over-diameter ratio, benefited the piston-ring performance and, in addition influenced heat dissipation favorably.

The piston was a trunk-type design of an aluminum alloy produced by the permanent-mold process, cam ground, and with a solid skirt to withstand heavy gas pressures. Three compression rings with a chrome-plated top ring, two oil-control rings with one above and one below the center line of piston pin were used. The dome of the piston was gable-shaped with the surface sloping on the same angle as the valves in the cylinder head.

The connecting rods were unusually arranged for an engine of this size and type, so nearly approaching an aircraft engine in design and performance. They were steel forgings with I-beam-type cross section, shot-peened after machining. The rods were placed side by side, two per crankpin, operating on a common floating connecting-rod-bearing insert, which distributed the load and wear over the entire crankpin bearing surface, and also tended to decrease the bearing rubbing velocities. This design has long been a practice of the author's company in the V-8 type automotive engines. This arrangement also aided in balancing and standardizing for interchangeability by eliminating the usual fork-and blade assembly. The assembling of the rod to the piston was by the conventional method of a floating piston pin running in a bronze bushing pressed in the rod, lubricated only by splash and oil vapor.

The component parts that made up the cylinder-head assemblies, were the aluminum cast cylinder head with pressed-in- steel valve-seat inserts, camshafts, valve mechanism, and exhaust manifold.

The valve arrangements and mechanism were such that four valves were used per cylinder, two intakes and two exhausts, actuated by two overhead camshafts, with splined, bolted-on bronze gears operated by a common steel worm gear in each bank head. One shaft operated the intake valves while the other the exhaust valves. Special nonadjustable push rods were used, guided in a cup with a protruded hollow stem that pressed into the cylinder head, which also served as a valve guide bushing. The tappet clearance was established during manufacture or overhaul, and since this clearance was established cold and was greater than the maximum normal expansion of the parts, it seldom required attention.

The intake manifolds were cast the full length and integral with the cylinder heads, open on each end, providing a flange that held the carburetor-adapter housing which, in turn, supported the two carburetors. The carburetors used, one at each end of the engine, were of the downdraft type with dual throats or Venturi with each carburetor supplying fuel to both manifolds. The carburetor linkage provides for delayed opening for one carburetor, to insure a more even supply of fuel during slow-speed operation and during the period of initial acceleration. In limiting the flow to one carburetor during this period of initial acceleration, sufficient velocity is assured to maintain a flow of fuel during the period when the manifold vacuum drops to the minimum. Each carburetor is equipped with a degasser for each Venturi. This is a small mechanism which is actuated by the manifold vacuum and provides an automatic shutoff of the fuel that would otherwise flow through the idle jets during the period of deceleration, when no fuel is wanted in the system. The degasser also reopens the idle jets when the manifold vacuum has recovered and idle operation is required. By this elimination the supply of fuel to the engine during the period of deceleration, "torching" or excessive burning and exploding of gas in the exhaust system is averted. This is quite necessary for tank operation to avoid detection by the enemy during night operation. The housings were likewise connected to the exhaust system whereby the fuel-air mixture was heated, in addition to the heat received from passing through the intake manifold, adjacent to the water jacket of the cylinder head. This arrangement proved its merit both in performance and fuel economy, especially when operating the engine at slower speeds in cold climates.

The exhaust manifolds were made of a stainless-steel design, stamped in two halves and welded. This produced an exceptionally light part which normally would be of cast iron, thus saving quite a bit of weight. The manifolds were bolted on, one on each cylinder head assembly, and handled as part of that unit.

The accessory drive was a unit generally considered by many as one of the most interesting subassemblies of the engine. This unit was a small package consisting of an aluminum bracket supporting enough gears to provide for seven individual take-offs; namely, the hour-glass worm gear driving the two camshaft drives, one for each bank; the three bevel gears providing the two fan drives, one for each side of the engine; the magneto-drive pimion; the water-pump drive; and the oil-pump drive.

This assembly was bolted to the cam-drive end of the crankcase driven by a wuill shaft splined into the crankshaft. This quill shaft functioned as a cushion against torsional vibrations of the crankshaft that would normally be transmitted to the gear unit. In addition to the foregoing it also functioned as a fuse, if the loads imposed on the assembly exceeded the design limitations of 90 hp.

The aluminum-casting end cover supported the two magnetos and the magneto-drive water-pump assembly.

The oil pan which was also an aluminum casting was ultimately designed in two compartments carrying the oil-intake screens and pipes with a double pump that was driven by a quill from the previously mentioned assessory drive, thus enabling removal of this whole assembly without disturbing any other part of the engine.

Not only was the engine designed in separate assemblies, but it was designed to operate on either or both banks of cylinders. This was made possible by supplying for the sources of ignition two four-cylinder magnetoes, each operating one bank of cylinders.

The high-tension wiring was carried to the camshaft covers via titeflex conduit. The camshaft cover, also an aluminum casting, was so designed that along with covering and sealing the camshafts, a trough between the two camshafts provided space for the spark-plug wiring as well as making accessible the spark plugs for maintenance and replacement. This trough was ultimately covered by a thin sheet-metal plate, thus protecting the wiring from becoming damaged, shielding against radio interference, and giving the engine a clean smooth appearance.

Production Plan Allows for Design Changes

Simultaneously with the testing and development program of the first engine, drawings were released to the shop to proceed with patterns and fixtures to produce this engine in quantities. While it was not yet ready to be produced in great numbers, it had been sufficiently tested to prove the merit of basic design and that it obviously had many features which the Ordnance Department felt were attractive for tank application.

Under the circumstances, it was of course expected that the early production engines would perhaps prove themselves "green" and would therefore require many minor, as well as major changes, for we were in effect taking an engine right from the drafting board and placing it in production.

An engineering and production release system was therefore provided to permit the greatest flexibility in executing design changes. As a result, during this early production period changes were accomplished rapidly and in harmony with the Army test program, Some changes being placed on production within a matter of hours.

The test program was well along when there came the urgent demand from all battle fronts for more tanks and more engines. The Ordnance Department, realizing that the Ford engine was still in the development stage and that progress was being made as fast as was humanly possible, presented the problem to the management.

Orders were immediately issued to produce, as soon as possible, 50 engines with all parts made in the production departments. This order naturally accomplished its purpose, having quite an effect on both production and engineering. Engineering hastened to incorporate the latest developments as revisions, while production made sure its patterns and fixtures were accordingly brought up to date and finished.

As it worked out, the shop made a few attempts to change the design while engineering blamed the production quality for some of the misfits and failures of engine parts. Actually, production did offer some excellent suggestions, many of which were immediately adopted. The complaints that many of the parts were difficult to assemble and sometimes failing due to engineering faults, did diminish as the quality and methods of production improved.

During the building of the first engines it was found necessary to maintain an extremely close co-ordination between the designing, testing, manufacturing, and assembling of the engines. This was done to insure no loss of time in making and enforcing any improvements, especially when deficiencies were discovered that would jeopardize the operation of the engine.

Changes made in the engine up to this point admittedly were many, both in design and production. Improvements in bearings, connecting rods, piston materials, valves, tappers, etc., were all contributory to the longer life and durability of the engines which were so desperately needed to pass the Ordnance Department's engine-acceptance test.

Acceptance Tests

The acceptance test of 50 hr at full throttle and partially at simulated road load, was made and completed. However, the Ordnance Department did not stop there. It wasn't long afterward that the Ford Co was asked to send a representative to both Chrysler and G. M. Diesel, where Ford engines were also on an endurance test. Incidentally, these two companies and Ford's were still in competition against each other at the various proving grounds throughout the country.

Comments received from these testing facilities were mainly that this engine, and eight-cylinder 60-deg V-type, had inherently a secondary out-of-balance force, and that its roughness would be highly undesirable. After considerable discussion within our own engineering department as to the comparison between a V-8 60-deg and a V-8 90-deg engine, it was agreed to carry out a complete comparative investigation. Layouts of a proposed V-8 90-deg engine were made, from which was produced a wooden mock-up for comparing its appearance with the V-8 60-deg engine. On completing the investigation, conclusions were reached that nothing could be gained in space requirements by this new design. The only advantageous feature was an engine that would be in balance, producing torsional vibrations of lower amplitude, and a critical speed at a higher range, neither important enough to substantiate the substitution of this new design, owing to the operating speed range of the engine, never exceeding 3000 rpm, while propelling the tank. For operation at higher revolutions, a pendulum damper was developed which was still in the experimental stage and discontinued with the end of hostilities.

Design Difficulties Corrected

In the latter half of November, 1942, it was decided by the U.S. Army Ordnance Department to conduct a series of endurance tests of the Model GAA Ford Tank Engine, one of these tests to be conducted by the Chrysler Corporation in the Tank Chassis Dynamometer Laboratory at the Detroit Tank Arsenal.

The tests were closely followed by an Ordnance representative and Ordnance observors were in constant attendance while the tests were being conducted. The test procedure was that specified by the Ordnance Department and entitled "Acceptance Test for Liquid Cooled Tank Engines". These tests, which were started on 17 November 1942, were covered in Chrysler Corporation Report No. T 60403.11.

Three Ford Models GAA V-S tank engines #404, 557 and #700 were tested in that order. The following are the general specifications of the engine:

Type............... 8 cylinder 60° "V"

Bore............... 5.40"

Stroke............. 6.00"

Displacement ...... 1100 Cubic inches

Compression Ratio . 7.5 to 1

Max. Torque .... 1100 lb. ft.

Rated H.P. (Gross). 500 at 2600 RPM

Weight .... 1470 lbs.

Cylinder Block .... One piece aluminum casting with dry steel liners.

Crankshaft	Cast alloy iron, 180° throws and integral counter-weights.
Main bearings	5 replaceable meaming steel back, .005-.012 silver alloy, flash treated with .0005 lead plate and indium, thrust at front (flywheel end).
Cylinder Head	Cast aluminum, integral intake manifolds, two overhead direct acting camshafts per head. 4 valves per cylinder, 2 intake, 2 exhaust.
Valve Timing	Exhaust opens 50° B.B.D.C., closes 10° A.T.D.C. Intake opens 5° B.T.D.C. closes 55° A.B.D.C. Valve lash non-adjustable, .028 cold.
Magneto Ignition ..	American Bosch One spark plug per cylinder, aircraft type.
Ignition Timing ...	10° B.T.D.C. Engine #404 -10° B.T.D.C. Engine #557 -10° B.T.D.C. Engine #700 - 5° B.T.D.C. set at 1° B.T.D.C. for 1300 RPM run.
Curburetion	Stromberg dual downdraft.
Connecting Rods ...	1 section forged, not finished all over.
Conn. Rod Bearings .	Full floating, steel back, .005 - .012 silver alloy, flash treated with .0005 indium.
Pistons	Cast aluminum - trunk type.
Piston Rings	Top compression ring chrome plated #2 and #3 compression rings plain, all 3/32" wide. #4 and #5 - oil control rings - 3/16" wide.
Piston Pin	Full floating.
Timing Gears	Lower end, bronze gear on crankshaft to steel worm on vertical drive upper end, steel worm to bronze gear on camshaft.

The equipment upon which these engines were tested is in reality a chassis dynamometer for testing a complete tank. The power absorption is accomplished with two eddy-current dynamometers, one at each final drive shaft. In order to handle first gear torque, speed increasing units with reaction scales are used between the final drive shaft and dynamometer.

The M4A3 tank was placed between the two dynamometers and the track and drive sprockets were removed. The universal joint propellor shafts were coupled to the drive shafts. The actual power output of the engine was measured at the engine companion flange by an electrical torsiometer. This torsiometer was used only to measure torque during performance tests. The absorption dynamometers were used to indicate torque output during the endurance testing, the various part load scale readings have been determined with the aid of the electric torsiometer.

In order to control the inlet cooling air temperatures, a blower with the required duct work was installed to make hot air recirculation possible. The balance of the hot cooling air was exhausted through the plant roof. The engine exhaust was first run into the same duct used for exhausting the cooling air. Later because of excessive noise, a separate exhaust pipe was installed which carried the exhaust through the plant roof.

To measure the blowby from the engine, a fitting was made to cap the crankcase breather outlet. A tube was led from this outlet to a gas-meter in the tank hull.

To measure intake vacuum, a mercury manometer was hung in the tank hull and connected in parallel to each intake manifold. The fuel consumption was measured by a Bowser type meter in the main supply line to the engine.

The first results of the tests showed that engine life was very unsatisfactory. During the tests progress was made in improving the engine until considerable increase in endurance life was obtained. However, there was still need for additional development to improve the engine.

Engine #404 did not complete the acceptance test because of failure of the main bearing webs in the block at 135 hours. This was a chronic weakness in other current engines of this model and was corrected by thicker web sections. In subsequent tests, this failure was not encountered.

Engine #557 did not complete the 250 hour acceptance test because of excessive oil consumption and blowby at 132-1/2 hours. This was caused by stuck and scored rings and by the fact that a retainer ring was left out of one piston pin hole causing the pin to score a cylinder wall quite deeply.

Engine #700 completed the 250 hour test successfully except that the accessory and camshaft drive gears were badly pitted. Subsequently the engine ran 116 more test hours when the main bearing caps and crankshaft failed and the test was concluded.

From the results of the maximum performance tests of the engines it was concluded that the wide open throttle net power output of the Ford Model GAA engine at the clutch companion flange at 2600 RPM with engine installed in the tank and driving the fans and generators was 453 brake horsepower. The maximum torque of the engine was 963 lb. ft. at 1950 RPM. These figures are for standard S.A.E. conditions of atmosphere.

There was no definite indication of less of power or torque during the 100 hour road load tests. The average loss of horsepower was .5% and torque, 1.5%. However, only one engine actually lost horsepower and torque while one gained 5 horsepower

There was no loss, but an actual gain in maximum performance of engine #700 over the full 250 hour test run indicating little loss in compression and a beneficial affect of decreased engine friction balanced against detrimental effect of head deposits, etc.

The average specific fuel consumption of .56 gallons per brake horsepower per hour at 2600 RPM was quite favorable for the engine.

The greatest impedement to the continous operation of the three engines was the recurring troubles with the ignition system. These troubles were fouling of spark plugs, insulation failure on ignition wires, and sticking of the magneto spark advance mechanism holding the spark constantly advanced. The ignition wiring was inside the cambox cover where temperatures approaching 300° F were measured. Some method for keeping these wires cool was needed to prevent breaking down of the insulation. The ignition timing of 10° B.T.D.C. was not satisfactory for all around operation. With this setting, detonation was excessive at 1300 RPM and still was present at 1900 RPM. Prolonged running at low speeds and high loads resulted in an eating away of the cylinder head combustion chamber walls. With a 5° B.T.D.C. spark setting, this erosion was still present.

On all three engines there was considerable scoring and pitting of the bronze worm gears in the camshaft drive train. These are the gears on the camshafts and the drive gear on the crankshaft. On engine #557, the crankshaft gear teeth were worn practically to a point.

There was some early difficulty with the carburetor mixture control caused by the carburetor accelerator pump being put in operation by engine vibration. This was cured by a heavier spring on the return mechanism.

In order to maintain oil temperatures at a 250° F maximum, it was necessary to provide artificial cooling even at road load. Indications were that an oil cooler was quite necessary for this engine.

Although not a part of the engine, the fan belts were a source of trouble which could lead to engine failure. One belt disintegrated completely during an initial 2900 RPM run. Several others were replaced just short of failure throughout the test.

The effects of a very considerable torsional vibration period in the driving range between 2100 and 2300 RPM were noted. Again, by general agreement, it was decided not to operate the engine continuously at 2200 RPM, but instead at 2300 RPM. This was a deviation from the prescribed procedure.

The original method of bolting on the main-bearing caps was more theoretically correct than practical. The arrangement of the studs was of a coaxial nature, pet-named "Corset lacing". The idea was excellent for its clamping characteristics but not adequate for preventing the fore-and-aft rocking of the bearing cap, believed to be caused by the deflection of the crankshaft pivoting at the main bearing.

The web condition came about and was accelerated by the fact that Ford Co. was using a block which was cast by an outside company, having the metallurigical characteristics and thickness of walls on the low side. This of course indicated that the block was not designed with enough margin of strength to accommodate the necessary varations in quality of metal, resulting from high-quantity production.

The crankcase was successfully improved and made rigid by increasing wall thickness and ribbing sections, and by providing deep-section main-bearing caps held in place by two vertical studs. This rigid crankcase was the beginning of a troublesome era of fatiguing and breaking of the crankshaft.

It was at this point that the development program of combining various formulas of steelmaking and heat-treatment was carried out to produce a sturdier crankshaft, ultimately and successfully manufactured on a production scale.

Aluminum engines, as is customary, do not use a gasket between cylinder head and block. In place of a gasket, grommets are inserted in carefully machined counterbores to seal any high-pressure oil or collant lines passing from the block to the cylinder heads. The handling of these grommets in assembly requires a great amount of care and skill successfully accomplished only by experienced mechanics.

The fact that the engines in tanks, because of the lack of skilled manpower, would have to be serviced by G. I.'s who in many instances never saw the inside of an engine, necessitated a more simple and practical approach. Another reason for eliminating excess machining was that these engines were produced on machinery and equipment that had once been discarded, and in many instances a half century old, used only because newer machinery was unobtainable at any price. Thus was introduced the usage of a one-piece asbestos-filled, metal-covered gasket, "grommetted" by steel rings around the cylinder bores and oil and water passages. This proved to be quite an improvement in overcoming oil and water leaks, heretofore unsuccessfully sealed with the rubber-grommet arrangement.

After having successfully developed the cylinder-head gasket, the Ford Co. was still bothered with rejection of engines because of oil leaks. In many instances oil was found mixed in with the coolant. To establish this cause another period of testing was undergone, in the course of which infinitely small pores were discovered in the casting of

APG Photograph 79619

March 24 1943

Project 4-28-1. Ford Tank Engine #1483, Model GAA.

Right rear view.

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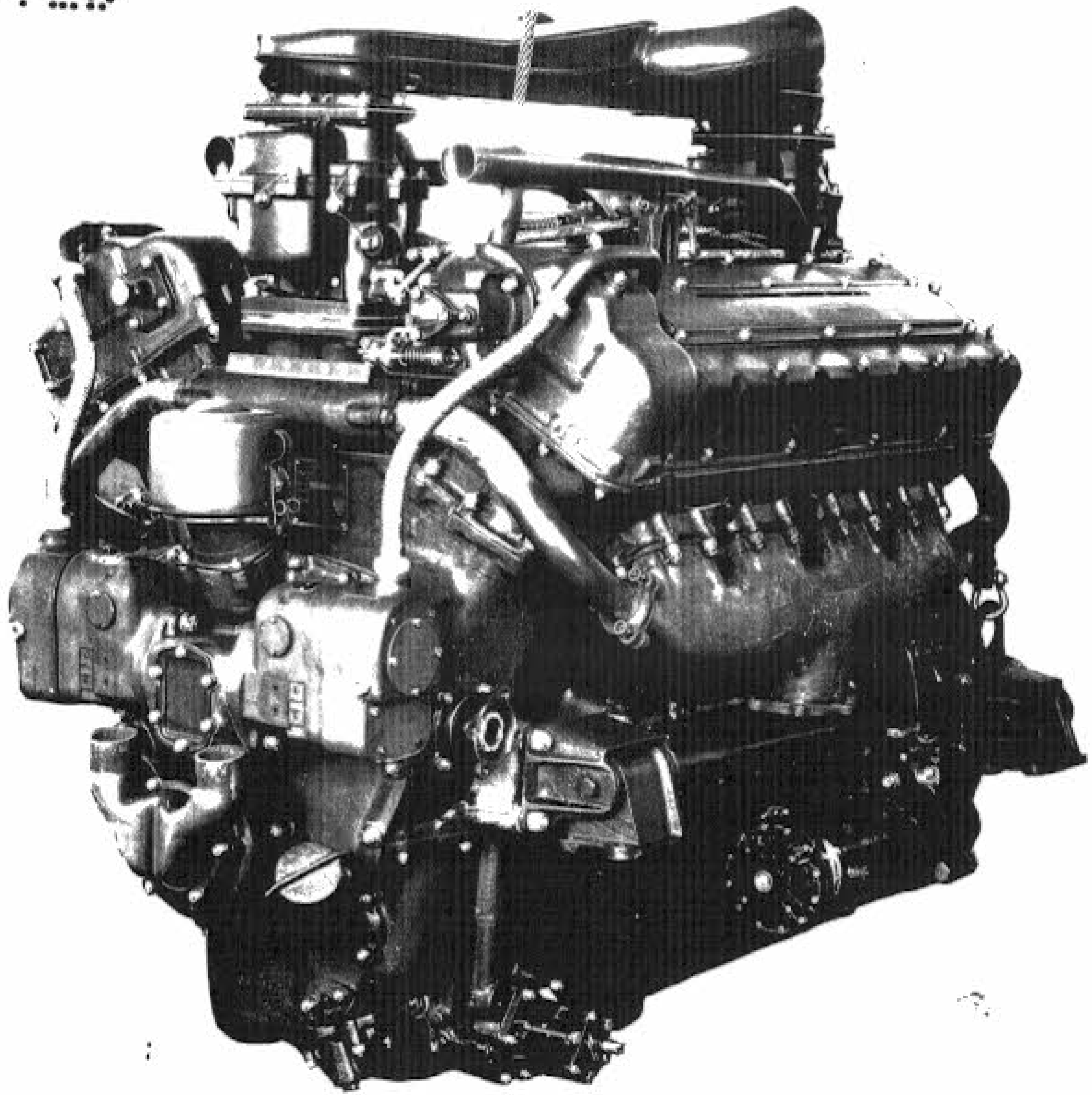


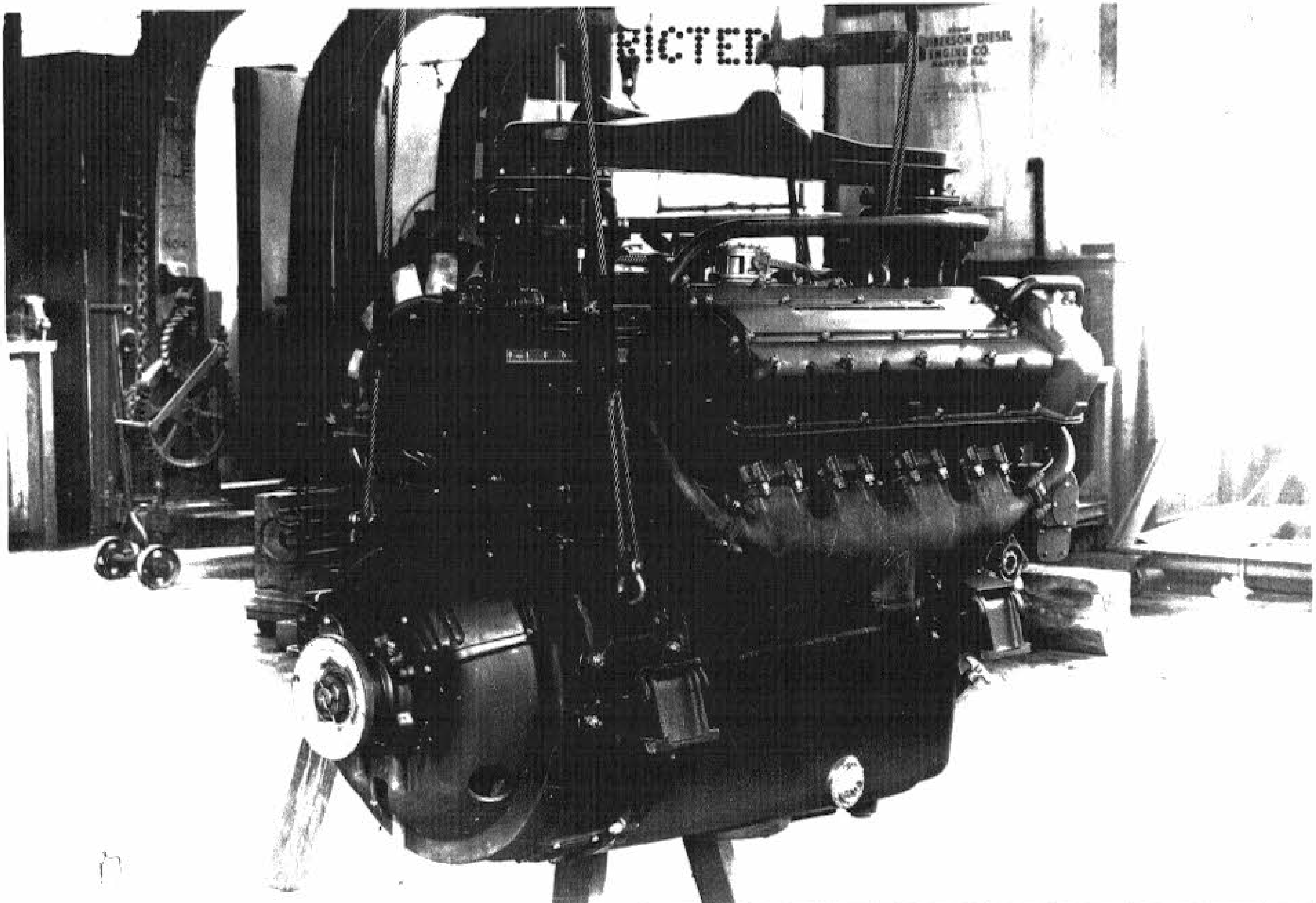
79619 3-24-43 ABERDEEN PROVING GROUND ORDNANCE DEPT.

Project 4-28-1. Ford Tank Engine #1483, Model GAA. Right rear view.

APG Photograph 79620

March 24 1943

Project 4-28-1. Ford Tank Engine #1483, Model GAA. Left front view.



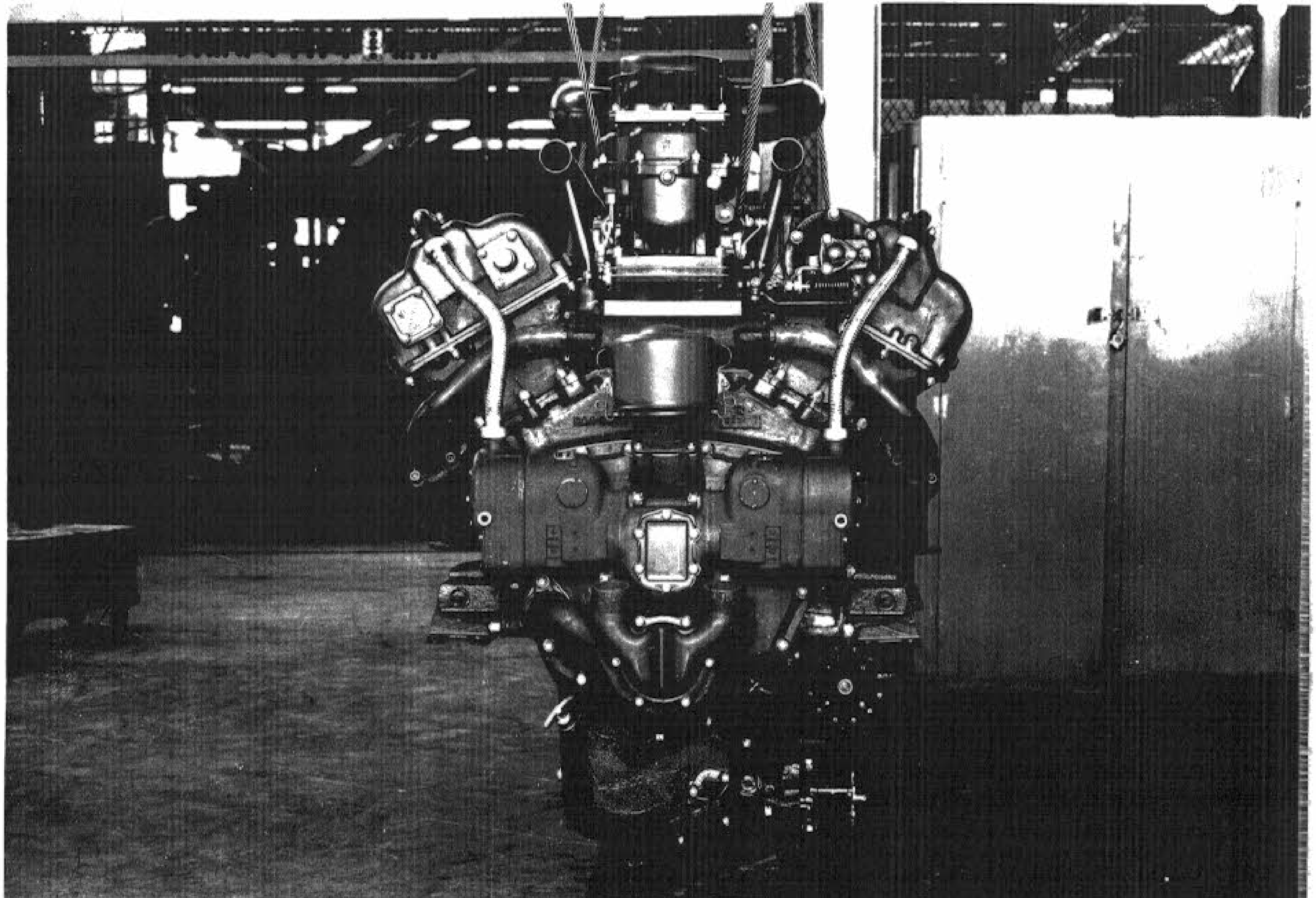
79620 3-24-43 ABERDEEN PROVING GROUND ORDNANCE DEPT.

Project 4-28-1. Ford Tank Engine #1483, Model GAA. Left front view.

APG Photograph 79621

March 24, 1943

Project 4-28-1. Ford Tank Engine #1483, Model GAA. Rear View.



79621 3-24-43 ABERDEEN PROVING GROUND ORDNANCE DEPT.

Project 4-28-1. Ford Tank Engine #1483, Model GAA. Rear view.

APG Photograph 79622

March 24 1943

Project 4-28-1. Ford Tank Engine #1483, Model GAA. Right side view.

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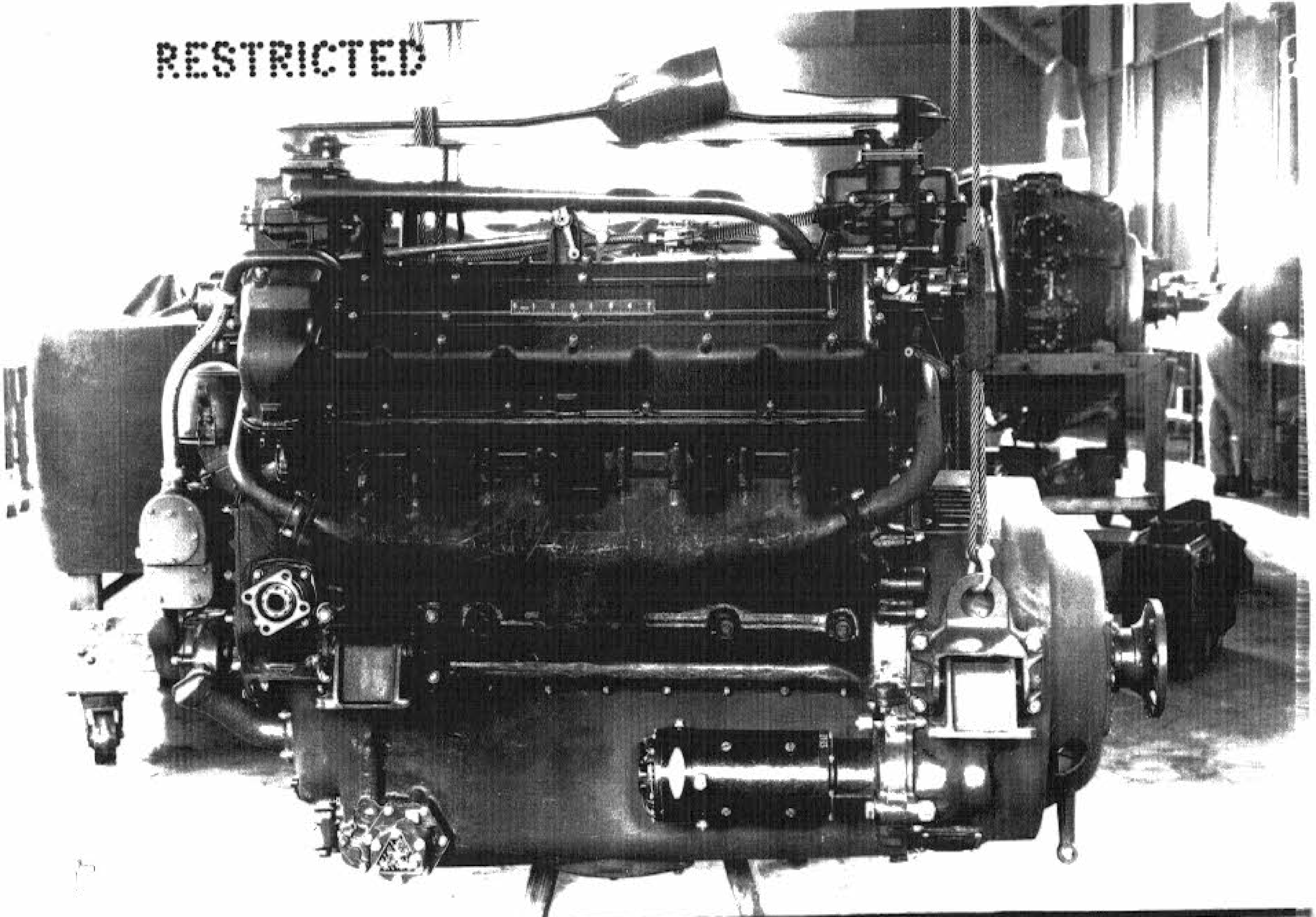

79622 3-24-43 ABERDEEN PROVING GROUND ORDNANCE DEPT.
Project 4-28-1. Ford Tank Engine #1483, Model GAA. Right side view.

APG Photograph 74805

December 8, 1942

3" Gun Motor Carriage, M10A1, Pilot (Ford). Left top, gun in traveling position.

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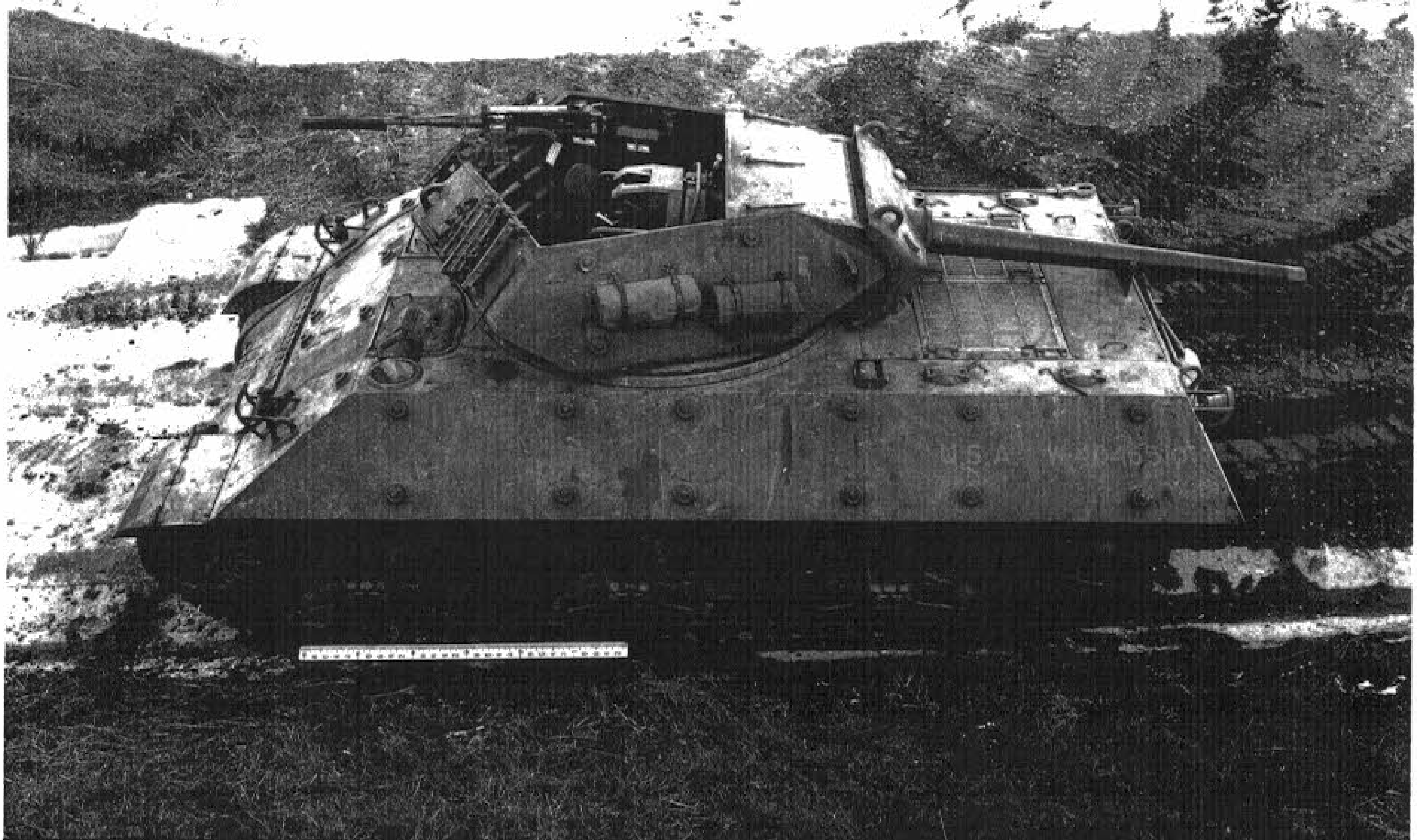


74805 12-8-42 ABERDEEN PROVING GROUND ORDNANCE DEPT.

3". Gun Motor Carriage, M10A1, Pilot (Ford). Left top, gun in traveling position.

both cylinder block and cylinder heads. To overcome this condition Ford metallurgical laboratory developed an impregnation process with a silica-gel treatment, which was used very successfully.

While Chrysler Corporation was conducting its tests on the Ford GAA engine, Aberdeen Proving Ground was also carrying-out an endurance test on these engines. This test was conducted from 7 November 1942 to 28 May 1943, as reported in "First Report on Ford Tank Engine Endurance Test "(APG-20-42, dated 31 July 1943).

The object of this test was to discover the defects affecting durability and mechanical reliability of the Ford Model GAA Tank Engine. Furthermore, to secure other pertinent information, deemed advisable, as the test progressed.

The Ford Model GAA Tank Engine (see APG. Photographs #79619 to #79622 inclusive), was used for the power plant in Medium Tanks M4A3 and Gun Motor Carriages M10A1.

The engines operated were Nos. 14, 23, 163, 380, 645, 715, 1483, and 1600. Design changes incorporated in these engines were as follows:

(1) Engine #14-basic Model GAA Tank Engine except the installation of Garlock packing in front crankshaft bearing seal.

(2) Engine #23-Same as above except change to Belmont Rubber core packing in front crankshaft bearing seal. Also Victor oil seals used on accessory drive output shafts.

(3) Engine #163 -this was first engine with five ring pistons. Garlock type packing was used on the front main bearing seal.

(4) Engine #380 -was equipped with Belmont Rubber core front main bearing seal. Victor type oil seal used on the accessory driveshafts then standard.

(5) Engine #645 -this is the first engine in which any changes had been made to increase strength of cylinder block casting. It had what is known as type A cylinder block in which vertical webbing carrying main bearings was increased from .4" to .64"thickness. Side anchor bolt bosses increased from 1.62" to 2" diameter.

(6) Engine #715 -this engine had type B cylinder block which in addition to reinforcement mentioned for type A had increased thickness of horizontal flange at bottom of main bearing webbing from .3" thickness to .5" thickness. This engine carried brass screw plugs in cylinder core holes in place of aluminum screw plugs heretofore used. Top compression piston rings were chrome-plated which is standard from there onward.

(7) Engine #1483 -had type C cylimder block which in addition to reinforcements mentioned under A and B had increased thickness of top wall of crank chamber from .#2 to .42". This engine had first revision in crankshaft where all journal to cheek fillets were increased from .105" - .115" to .140" - .150". Core hardness of shaft decreased

from 286 - 321 Brinell to 255 - 286 Brinell. Nitride case thickness of crankshaft increased from .010" to .020". Starter ring gear of type 4E oil hardness steel. Independent oil lead to magneto gears. Connecting rods of increased section, and shot blast operation added. Valve stems under-cut below head to eliminate sticking from carbon formation. Oil slinger added to water pump. High tension wires with steel tube reinforcements to spart plug terminal. Cylinder head joints sealed with Vickers hydraulic seals. Magneto gears 11 pitch 45° spiral (previously 30°). Valve push rods one piece #9 steel castings instead of two piece white iron foot with steel side wall as formerly used. Camshaft drive assemblies with steel gear on crankshaft and bronze gears on vertical shaft, in place of bronze gear on crank and steel on vertical shafts as formerly used.

(8) Engine #1600 -equipped with piston rings with large chamfer on upper inner corner for the purpose of increasing pressure on lower outer corner. All other items are the same as Engine #1483.

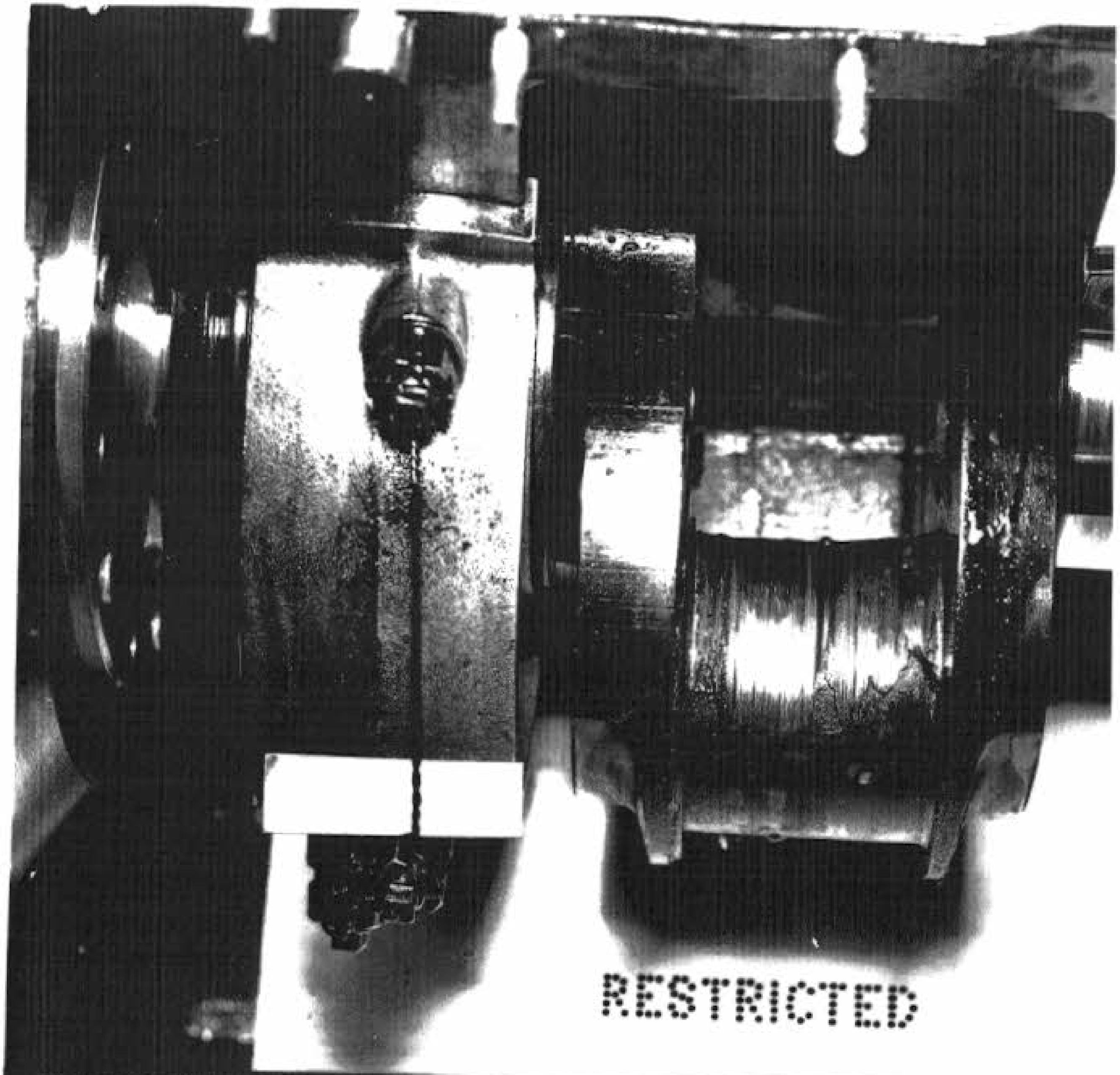
Engines #14, #380, and #715 were tested in Gun Motor Carriage M10A1 #1801. Engines #23 and #1483 in Medium Tank M4A3 #2968. Engine #163 in Gun Motor Carriage M10A1 #1802. Engines #645 and 1600 in Medium Tank M4A3 #11570. All vehicles were loaded to approximately 63,000# with full fuel tanks, less a crew of three.

Most of the operation was conducted on the level concrete and cross-country courses in the Perryman Test Area, the cross-country course having ditches and water hole obstacles. All engines, with

APG Photograph 73355

November 10 1942

Project 4-28-1. Gun Motor Carriage, M10A1, #1801. Ford Tank Engine Model GAA-V8, #14. View of number four connecting rod bearing after engine seized at odometer 566.



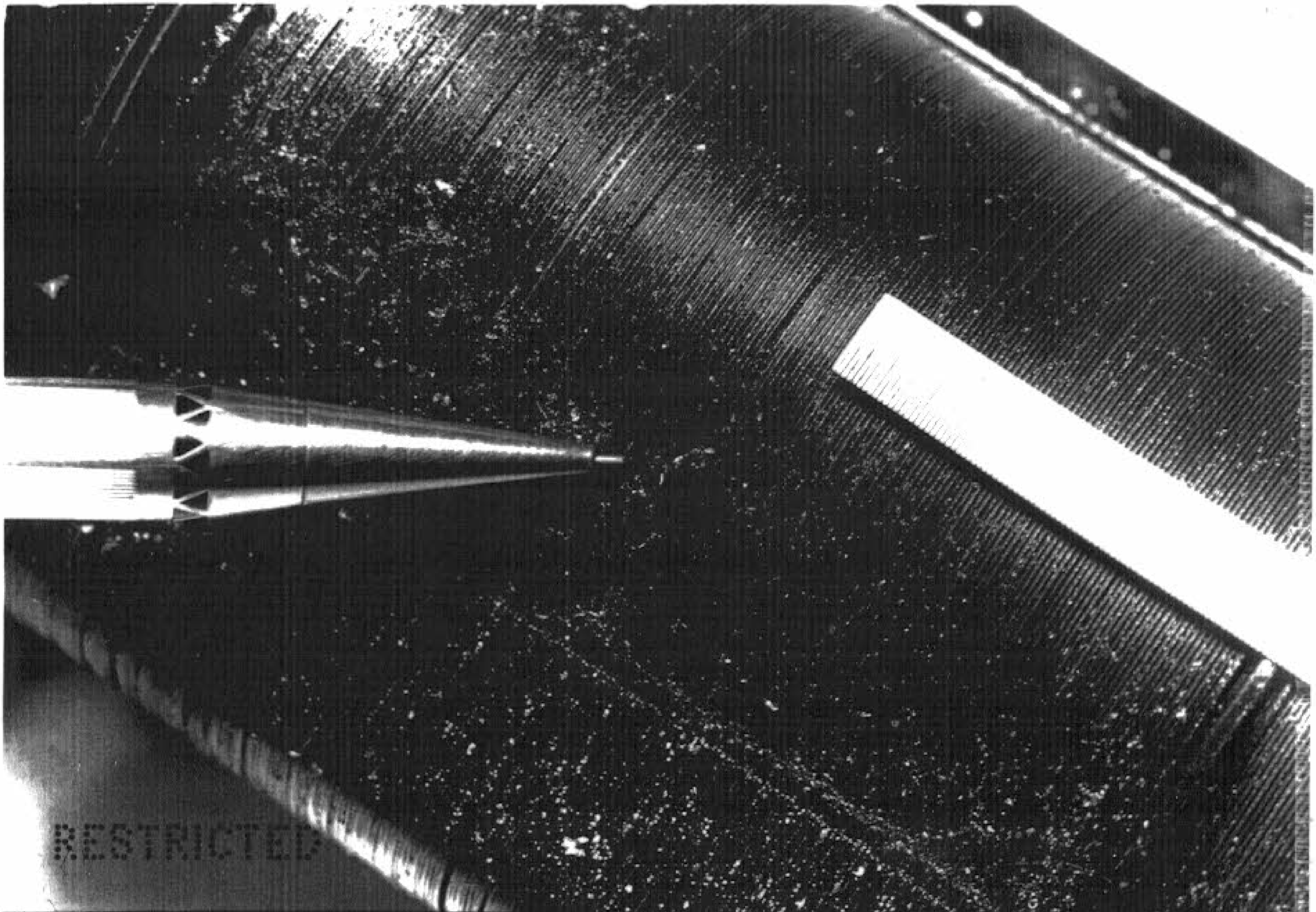
73355 11-10-42 ABERDEEN PROVING GROUND

Project 4-28-1. Gun Motor Carriage, M10A1, #1801. Ford Tank Engine Model GA... connecting rod bearing after engine seized at odometer 566.

APG Photograph 73356

November 10 1942

Project 4-28-1. Gun Motor Carriage, M10A1, #1801. Ford Tank Engine Model GAA-V8, #14. View of broken leaf of Cuto Automatic Oil Filter removed from seized engine at odometer 566.



73356 11-10-42 ABERDEEN PROVING GROUND ORDNANCE DEPT.

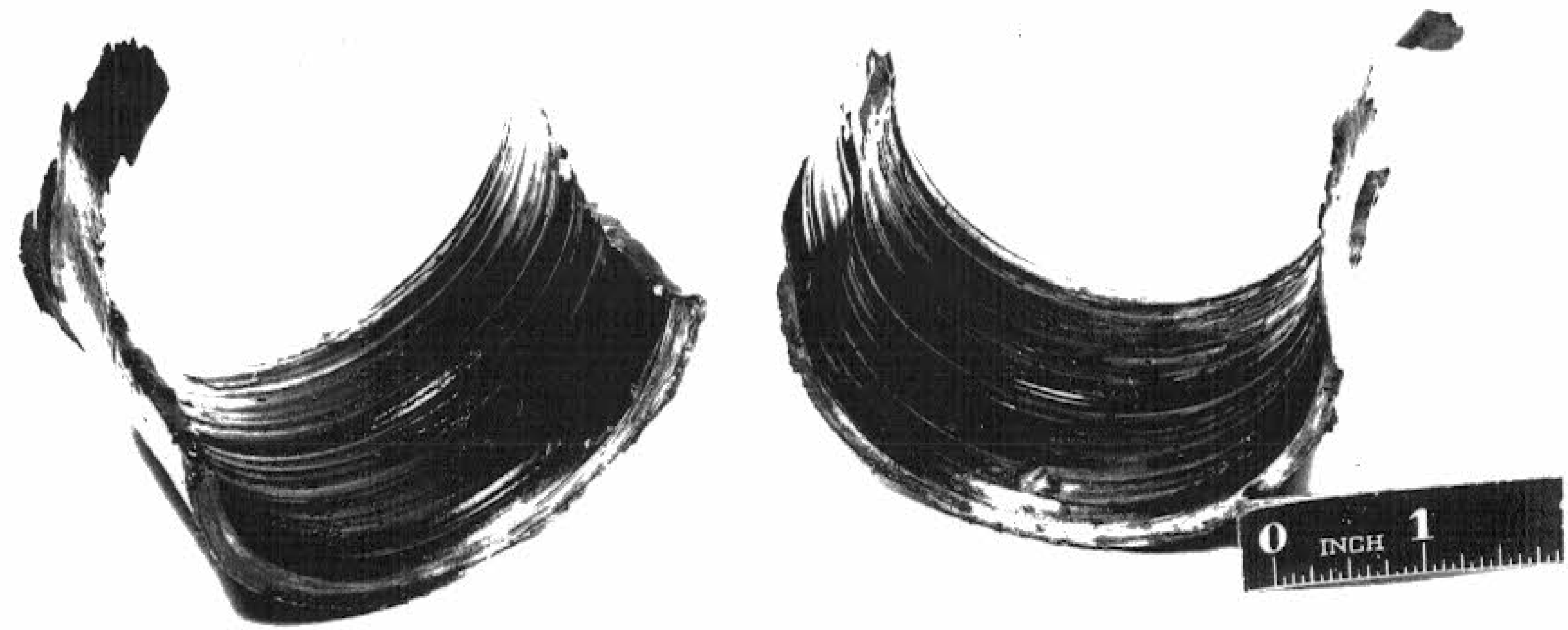
Project 4-28-1. Gun Motor Carriage, M10A1, #1801. Ford Tank Engine Model GAA-V8, #14. View of broken leaf of Cuto Automatic Oil Filter removed from seized engine at odometer 566.

APG Photograph 73357

November 10 1942

Project 4-28-1. Gun Motor Carriage, M10A1, #1801. Ford Tank Engine Model GAA-V8, #14. View of connecting rod bearings after engine seized at odometer 566.

RESTRICTED



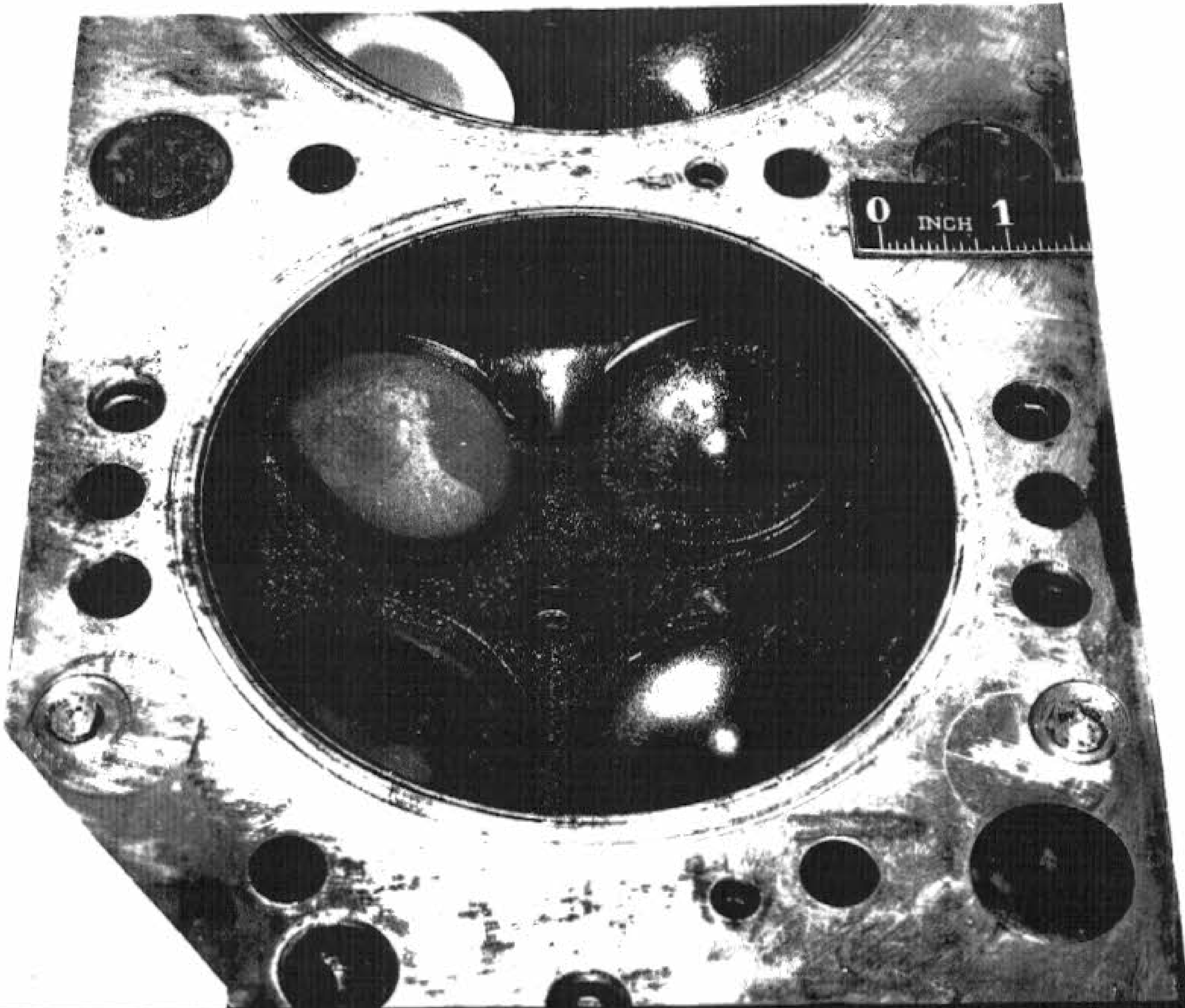
73357 11-10-42 ABERDEEN PROVING GROUND ORDNANCE DEPT.

Project 4-28-1. Gun Motor Carriage, M10A1, #1801. Ford Tank Engine Model GAA-V8, #14. View of connecting rod bearings after engine seized at odometer 566.

APG Photograph 73358

November 10 1942

Project 4-28-1. Gun Motor Carriage, M10A1, #1801. Ford Tank Engine Model GAA-V8, #14. View of cylinder head showing where piston had hammered against it. Engine siezed at odometer 566.



73358 11-10-42 ABERDEEN PROVING GROUND ORDNANCE DEPT.

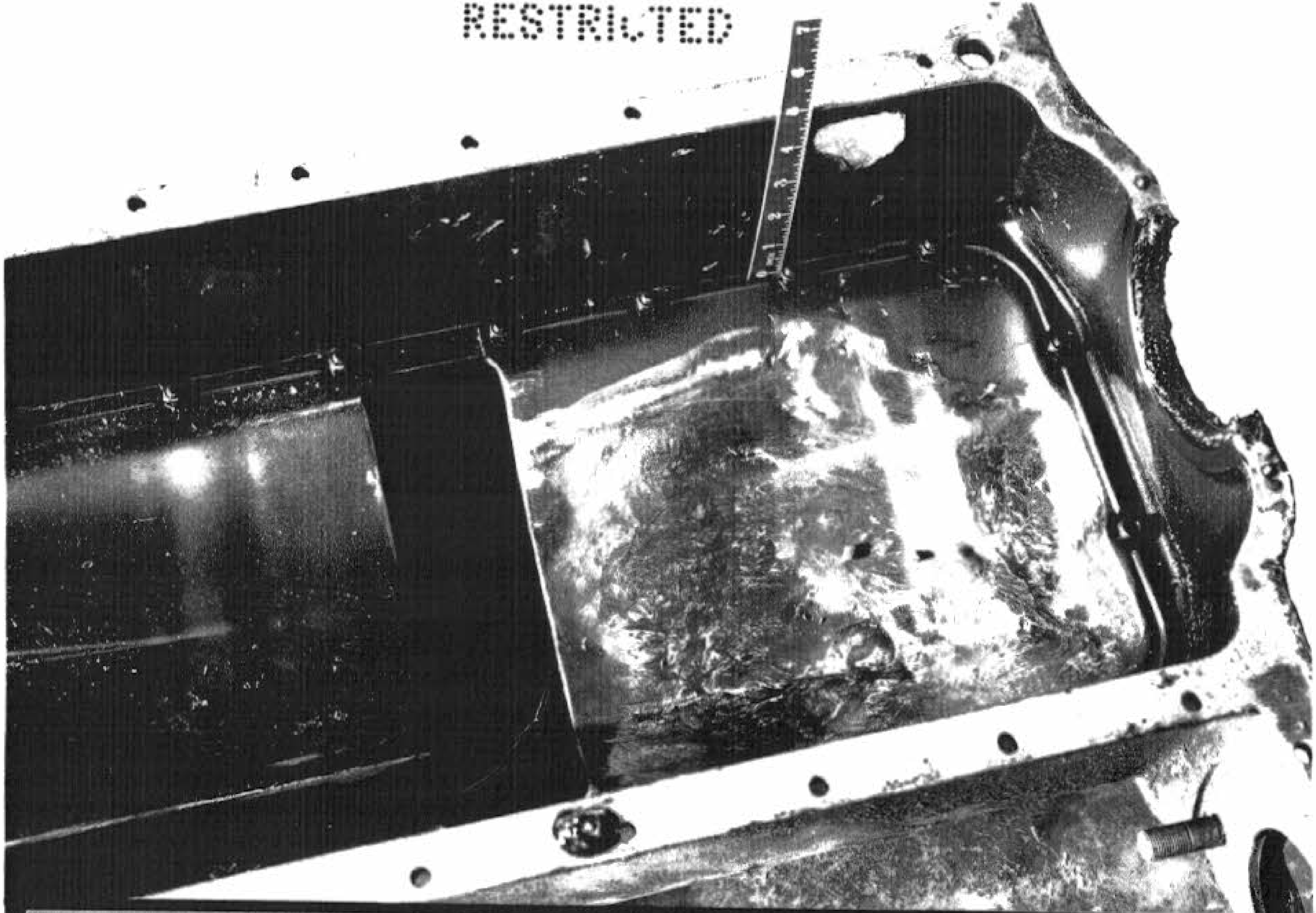
Project 1-PZ-1. Gun Motor Carriage, M10A1, #1801. Ford Tank Engine Model GAA-V8, #1[illegible]. View of cylinder head showing where piston had hammered against it. Engine seized at odometer 566.

APG Photograph 77627

February 12 1943

Proj. 4-28-1. Ford Tank Engine #23, Medium Tank M4A3, #2968. Damage to pan caused by failure of a #4 main bearing stud, allowing anchor to come out. Failure at 379:35 engine hours.

RESTRICTED



77627 2-12-43 ABERDEEN PROVING GROUND ORDNANCE DEPT.

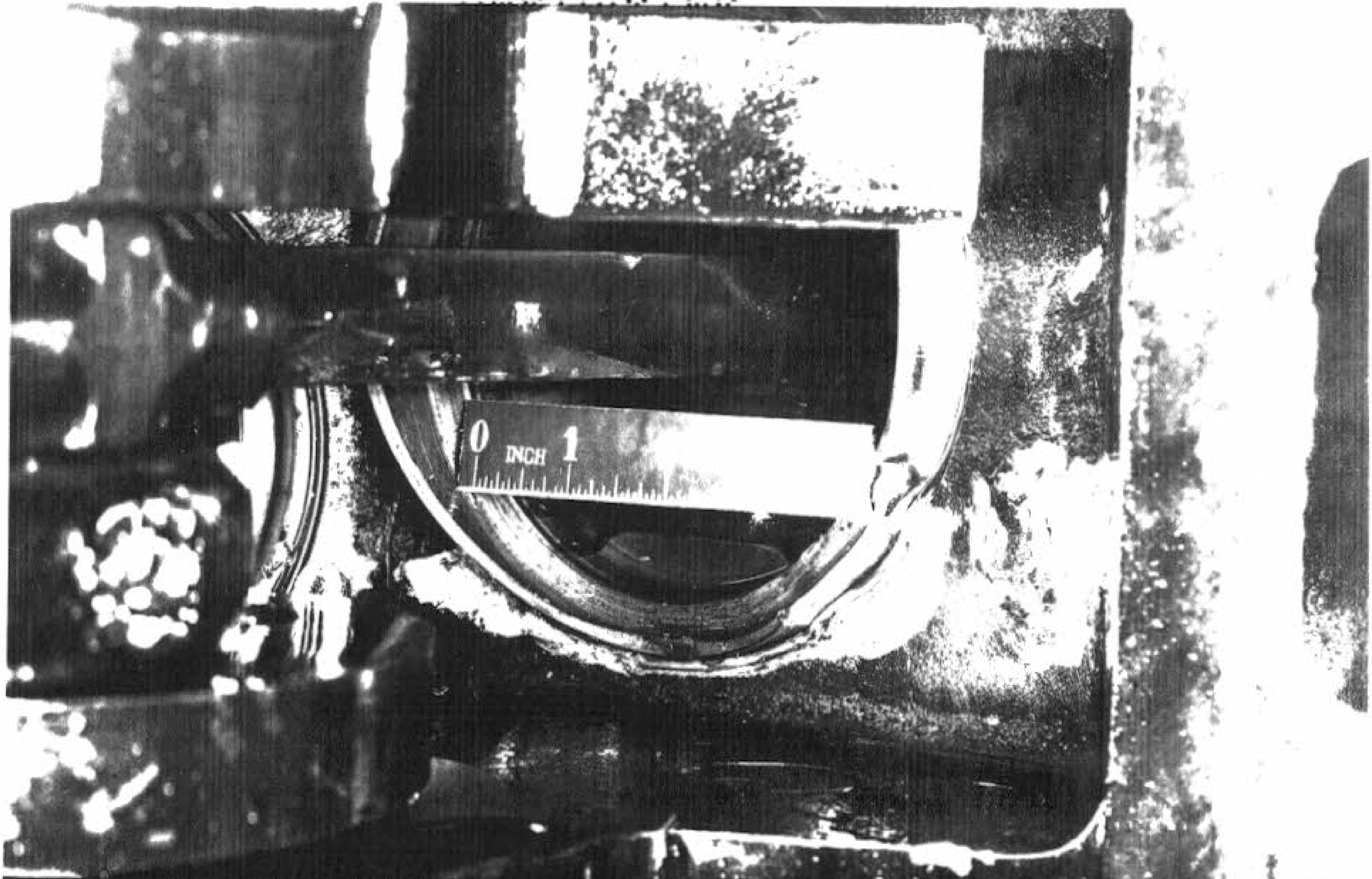
Proj. 4-28-1. Ford Tank Engine #23, Medium Tank M4A3, #2968. Damage to pan caused by failure of a #4 main bearing stud, allowing anchor to come out. Failure at 379:35 engine hours.

APG Photograph 77593

February 11 1943

Project 4-28-1. Ford Tank Engine #23, Medium Tank M4A3, #2968. Damage done to #4L cylinder and piston by a #4 main bearing stud anchor which came out when stud broke at 379:35 engine hours.

RESTRICTED



77593 2-11-43 ABERDEEN PROVING GROUND ORDNANCE DEPT.

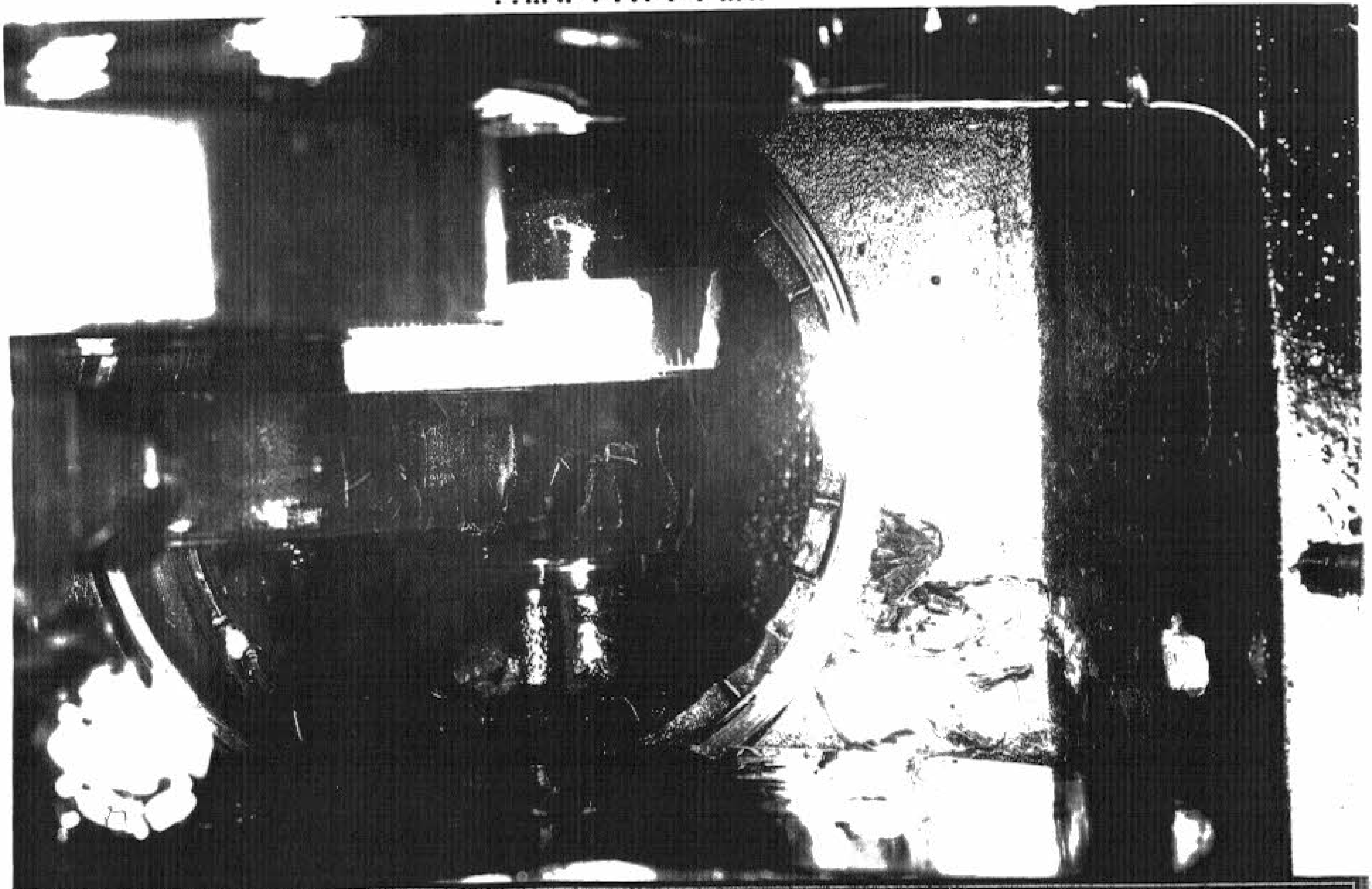
Project 4-28-1. Ford Tank Engine #23, Medium Tank M4A3, #2968. Damage done to #4L cylinder and piston by a #4 main bearing stud anchor which came out when stud broke at 379:35 engine hours.

APG Photograph 77594

February 11 1943

Project 4-28-1. Ford Tank Engine #23, Medium Tank M4A3, #2968. Damage done to #3L cylinder and piston by a #4 main bearing stud anchor which came out when stud broke at 379:35 engine hours.

RESTRICTED



77594 2-11-43 ABERDEEN PROVING GROUND ORDNANCE DEPT.

Project 4-28-1. Ford Tank Engine #23, Medium Tank M4A3, #2968. Damage done to #3L cylinder and piston by

APG Photograph 77595

February 11 1943

Project 4-28-1. Ford Tank Engine #23, Medium Tank M4A3, #2968. Broken #4 main bearing stud and anchor. Failure at 379:35 engine hours.

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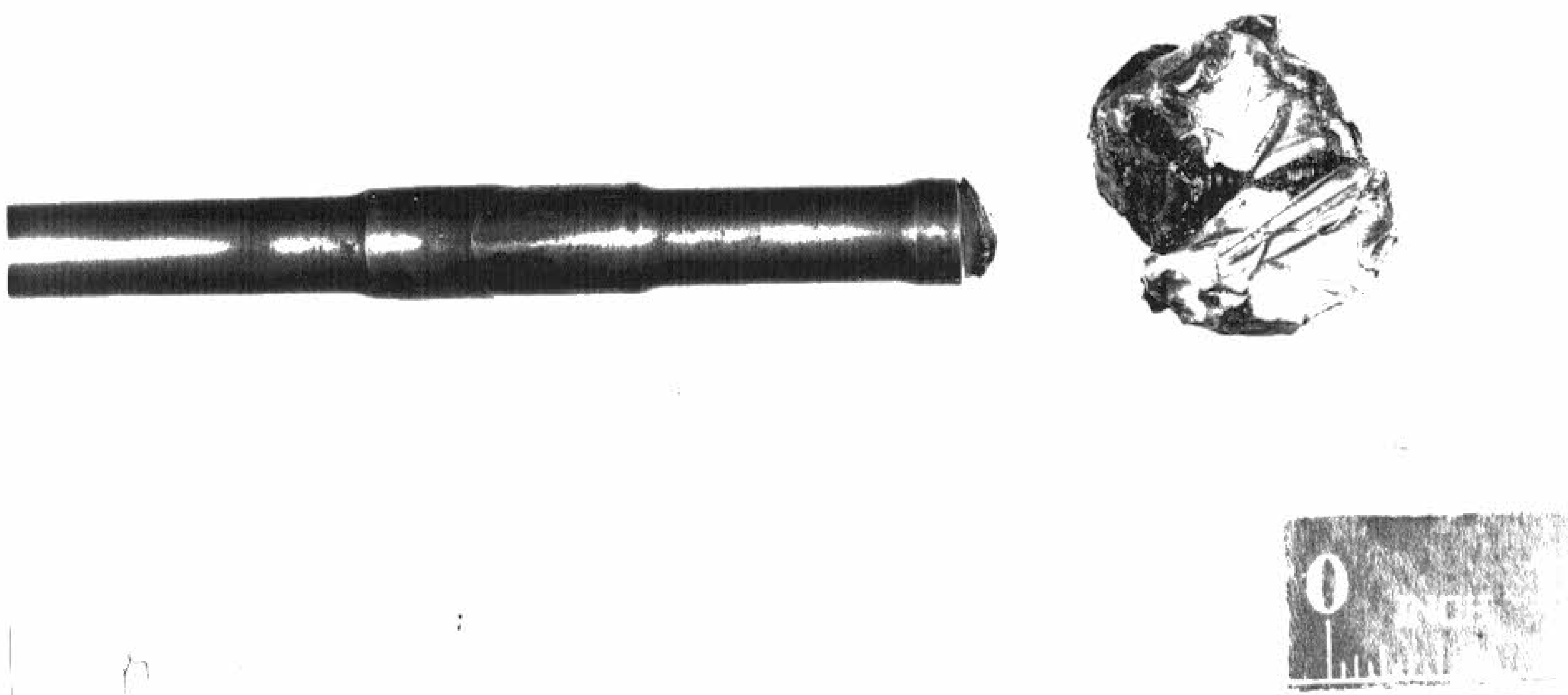

ABERDEEN PROVING GROUND — ORDNANCE DEPT.

77595 2-11-43

Project 4-28-1. Ford Tank Engine #23, Medium Tank M4A3, #2968. Broken #4 main bearing stud and anchor. Failure at 379:35 engine hours.

APG Photograph 77596

February 11 1943

Project 4-28-1. Ford Tank Engine #23, Medium Tank M4A3, #2968. Broken ends of #4 main bearing stud. Failure at 370:35 engine hours.

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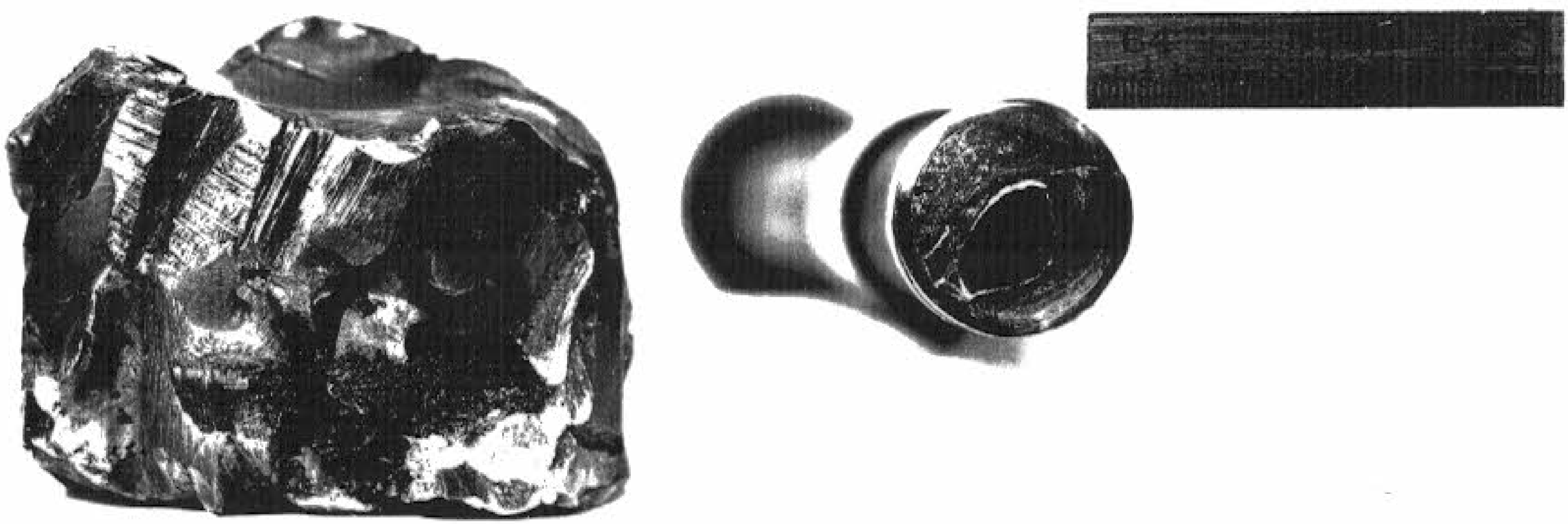


77596 2-11-43 ABERDEEN PROVING GROUND ORDNANCE DEPT.
Project 4-28-1. Ford Tank Engine #23, Medium Tank M4A3, #2968. Broken ends of #4 main bearing stud. Failure at 379:35 engine hours.

exception of #163 and #380 were shipped to the Lincoln Motor Company, Detroit, Michigan for inspection when a major failure occured or after having operated over 400 engine hours.

Reason for Termination of Engine Operation

(1) Engine #14 Number 4 connecting rod bearing failed after 39:35 hours of engine operation. See APG. Photographs #73355-#73358 inclusive.

(2) Engine #23 Number 4 left lower main bearing stud failed at the stud anchor after 379:35 hours of engine operation. Stud anchor dropped out of bearing web resulting in considerable damage to the engine. See APG. Photographs #76627 and #77593, #77596 inclusive.

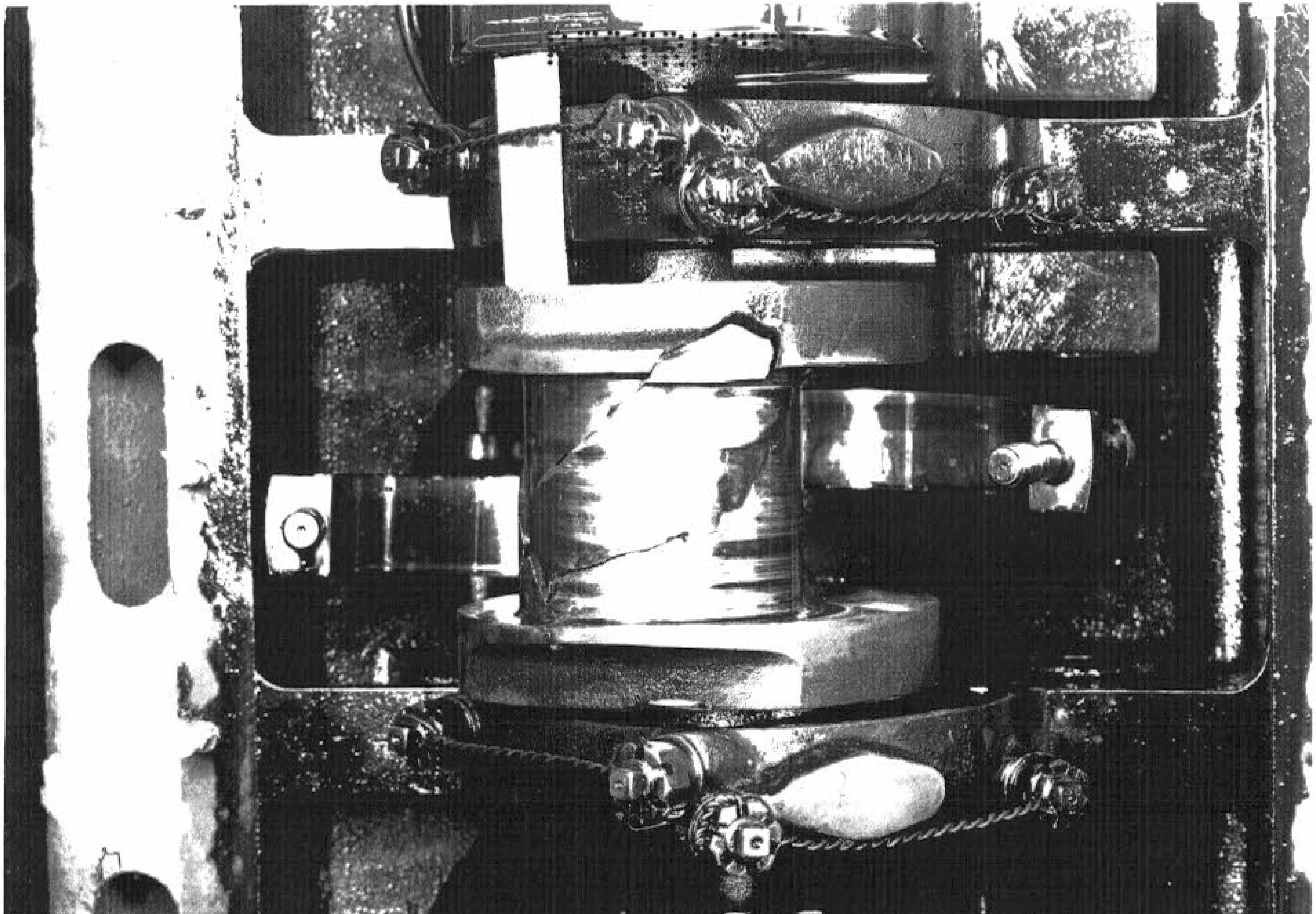
(3) Engine#163 Due to a fire in the engine compartment, because of an exhaust pipe failure, the radiator of the vehicle was damaged. The test was discontinued to await receipt of engines with type A Cylinder blocks.

(4) Engine#380 Left cylinder head failed, after 2:05 hours of engine operation. The test was discontinued to await receipt of engines with type A cylinder blocks.

APG Photograph 79799

March 23 1943

Project 4-28-1. Ford Tank Engine, #715. Crankshaft failure at #3 crank throw (355:00 engine hours).



79799 3-23-43 ABERDEEN PROVING GROUND ORDNANCE DEPT.

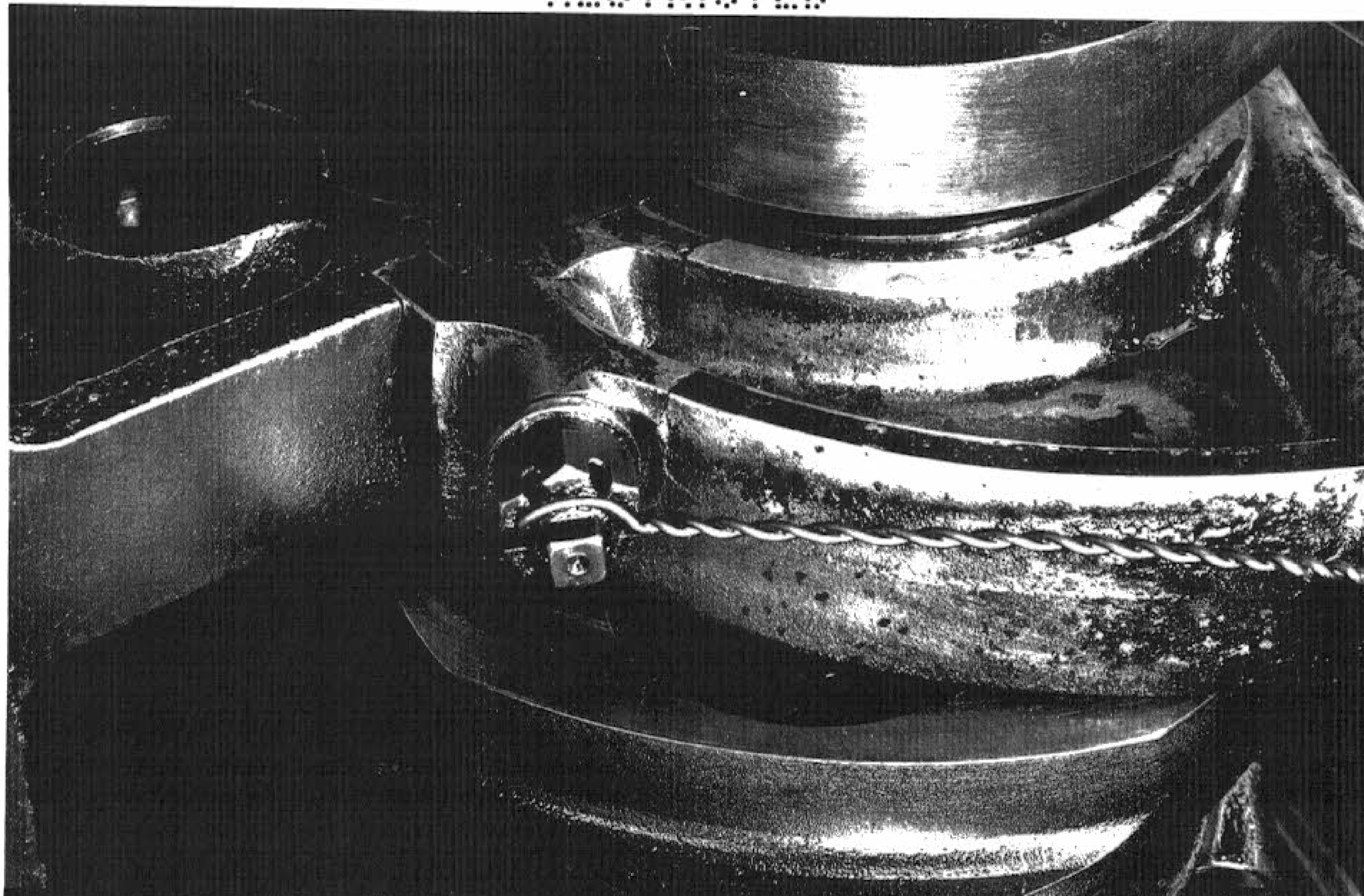
Project 4-28-1. Ford Tank Engine, #715. Crankshaft failure at #3 crank throw (355:00 engine hours).

APG Photograph 80003

March 27 1943

Project 4-28-1. 3" Gun Motor Carriage, M10A1, #1801, Ford Tank Engine, #715, No. 2 Main Bearing Cap. Note crack on No. 2 Main Bearing Cap (left side) under stud boss.

RESTRICTED



80003 3-27-43 ABERDEEN PROVING GROUND ORDNANCE DEPT.

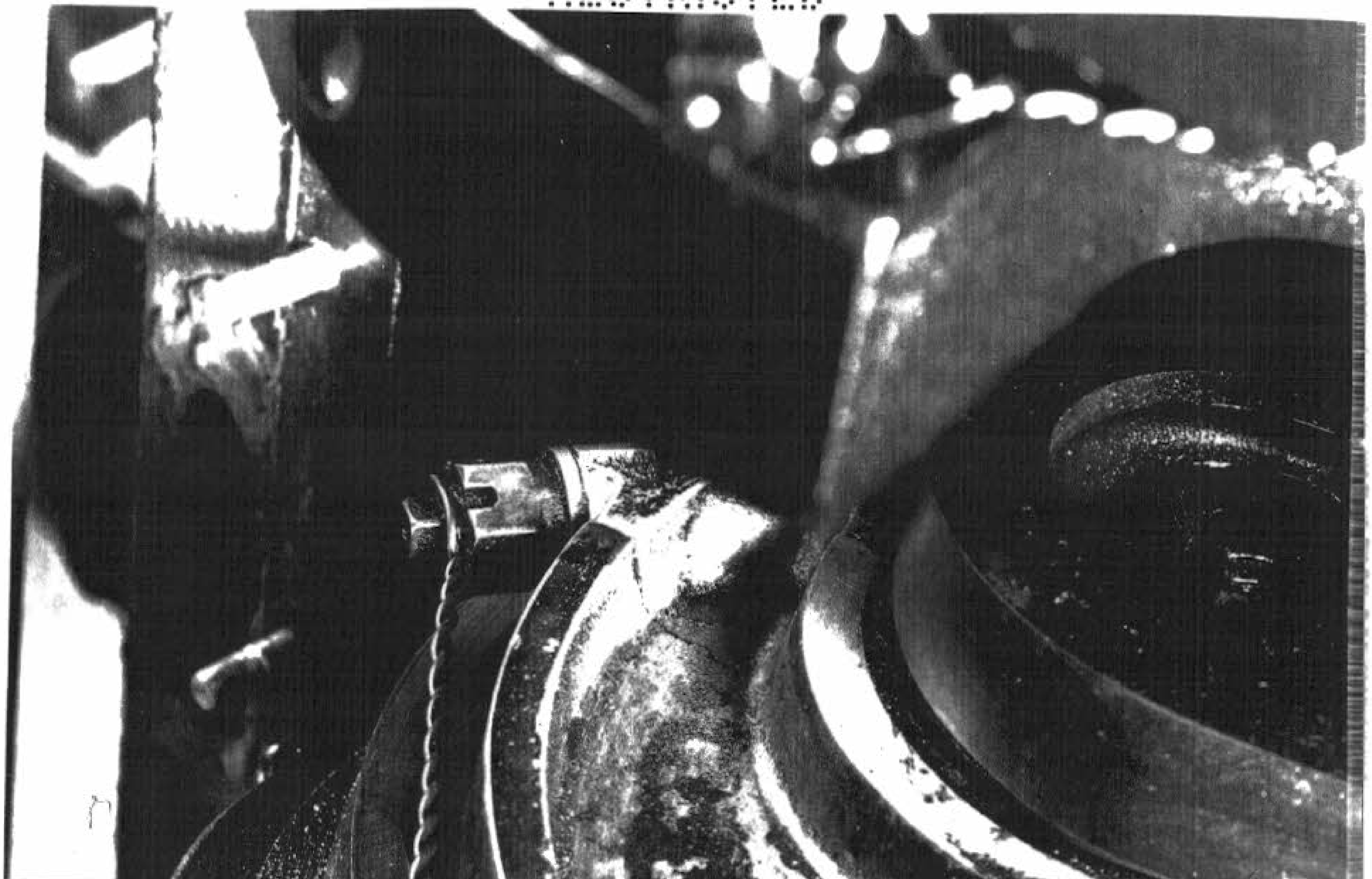
Project 4-28-1. 3" Gun Motor Carriage, M10A1, #1801, Ford Tank Engine, #715, No. 2 Main Bearing Cap. Note crack on No. 2 Main Bearing Cap (left side) under bearing stud boss.

APG Photograph 80003A

March 27 1943

Project 4-28-1. 3" Gun Motor Carriage, M10A1, #1801, Ford Tank engine, #715, No.2 Main Bearing Cap. Note crack on No. 2 Main Bearing Cap (left side) under bearing stud boss.

RESTRICTED



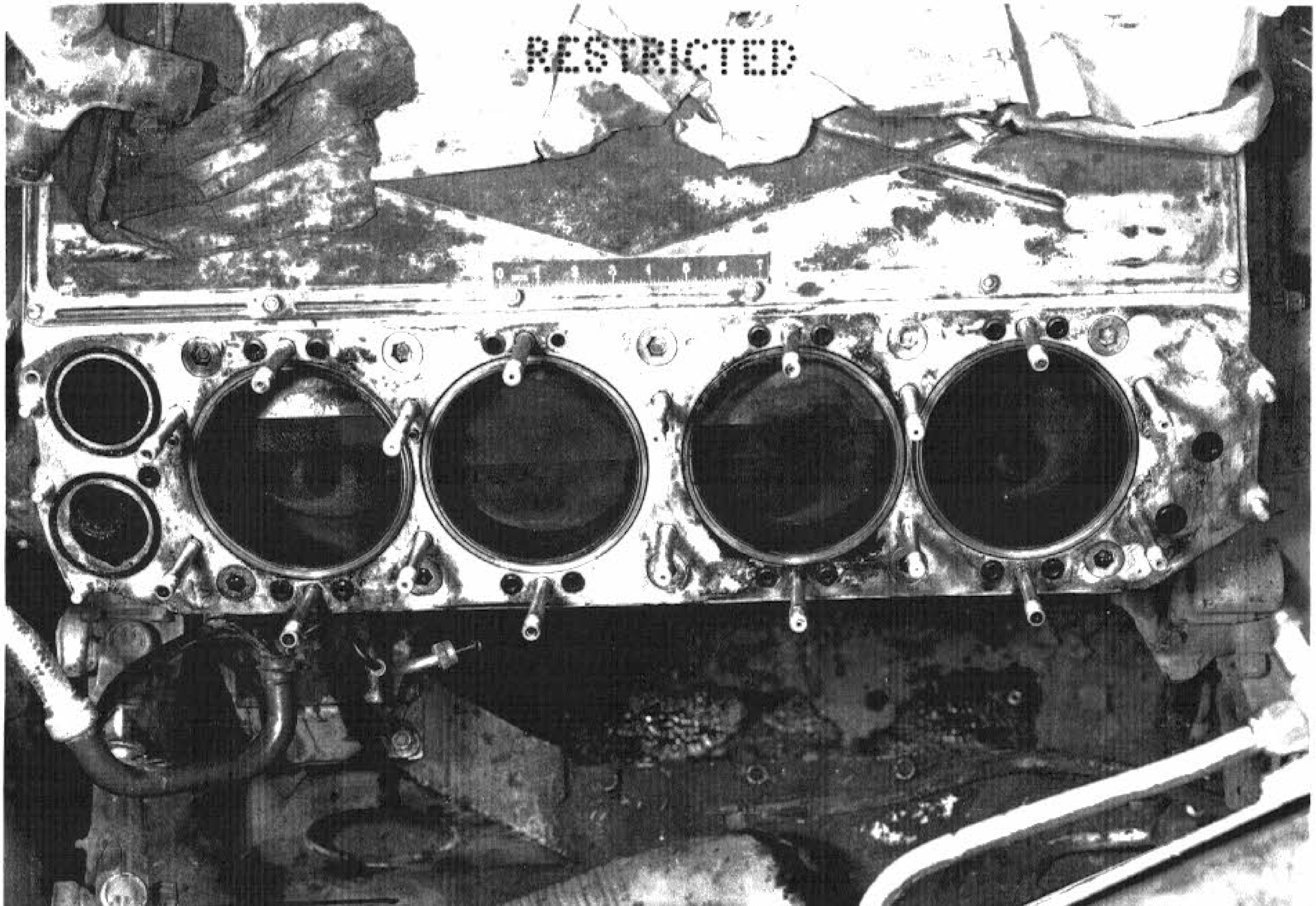
80003A 3-27-43 ABERDEEN PROVING GROUND ORDNANCE DEPT.

Project 4-28-1. 3" Gun Motor Carriage, M10A1, #1801, Ford Tank Engine, #715, No. 2 Main Bearing Cap. Note

APG Photograph 80086

April 7 1943

Cylinder Block, right bank, Ford Tank Engine, #1483, Medium Tank, M4A3, #2968. Engine hours: 108:50. Note condition of head gaskets.



80086 4-7-43 ABERDEEN PROVING GROUND ORDNANCE DEPT.

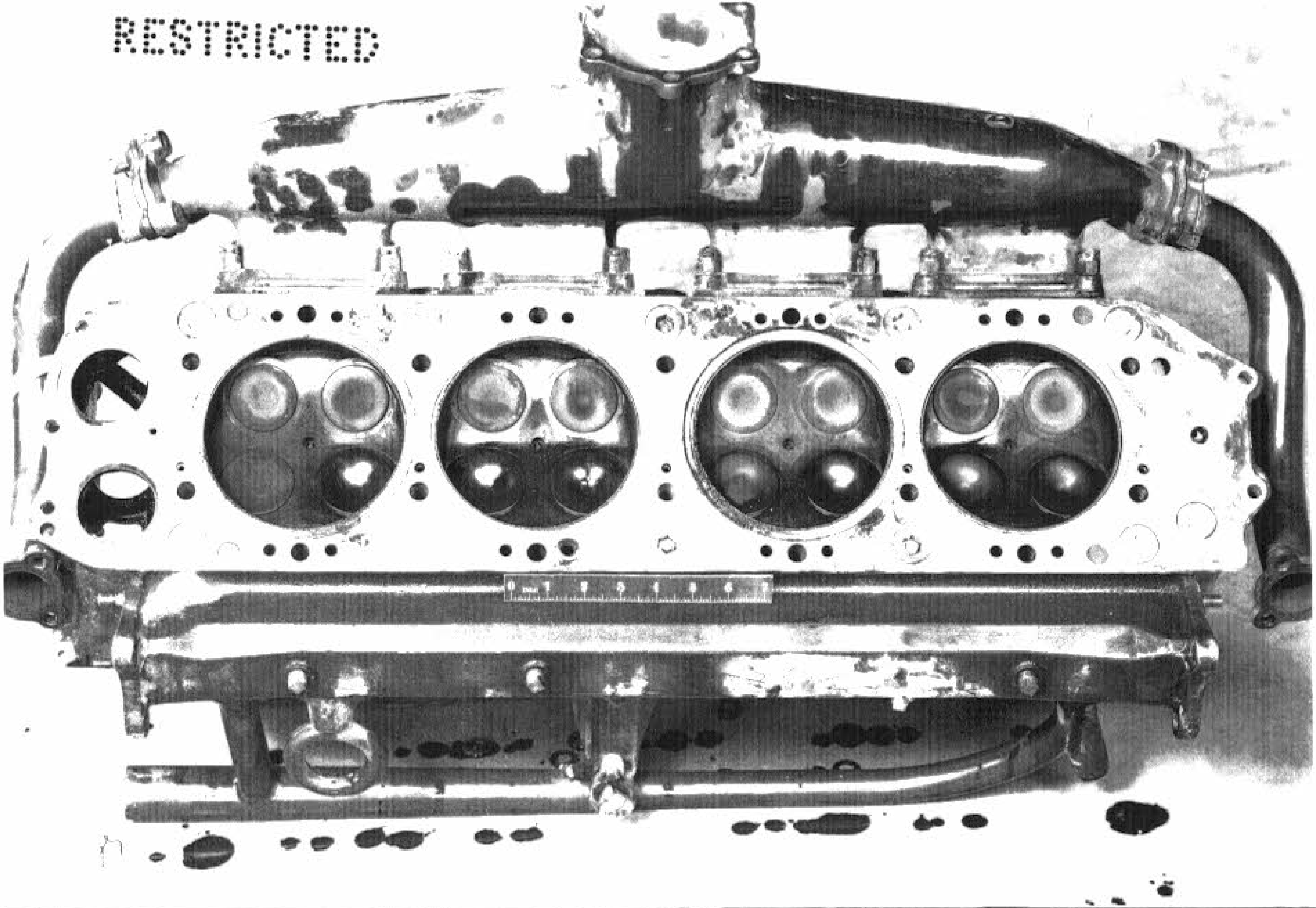
Cylinder Block, right bank, Ford Tank Engine, #1483, Medium Tank, M4A3, #2968. Engine hours: 108:50. Note condition of head gaskets.

APG Photograph 80087

April 7 1943

Right Cylinder Head, Ford Tank Engine, #1483, Medium Tank, M4A3, #2968. Engine hours: 108:50. Note condition of metal, intake valve side, of gasket contacting surfaces.

RESTRICTED



80087 4-7-43 ABERDEEN PROVING GROUND ORDNANCE DEPT.

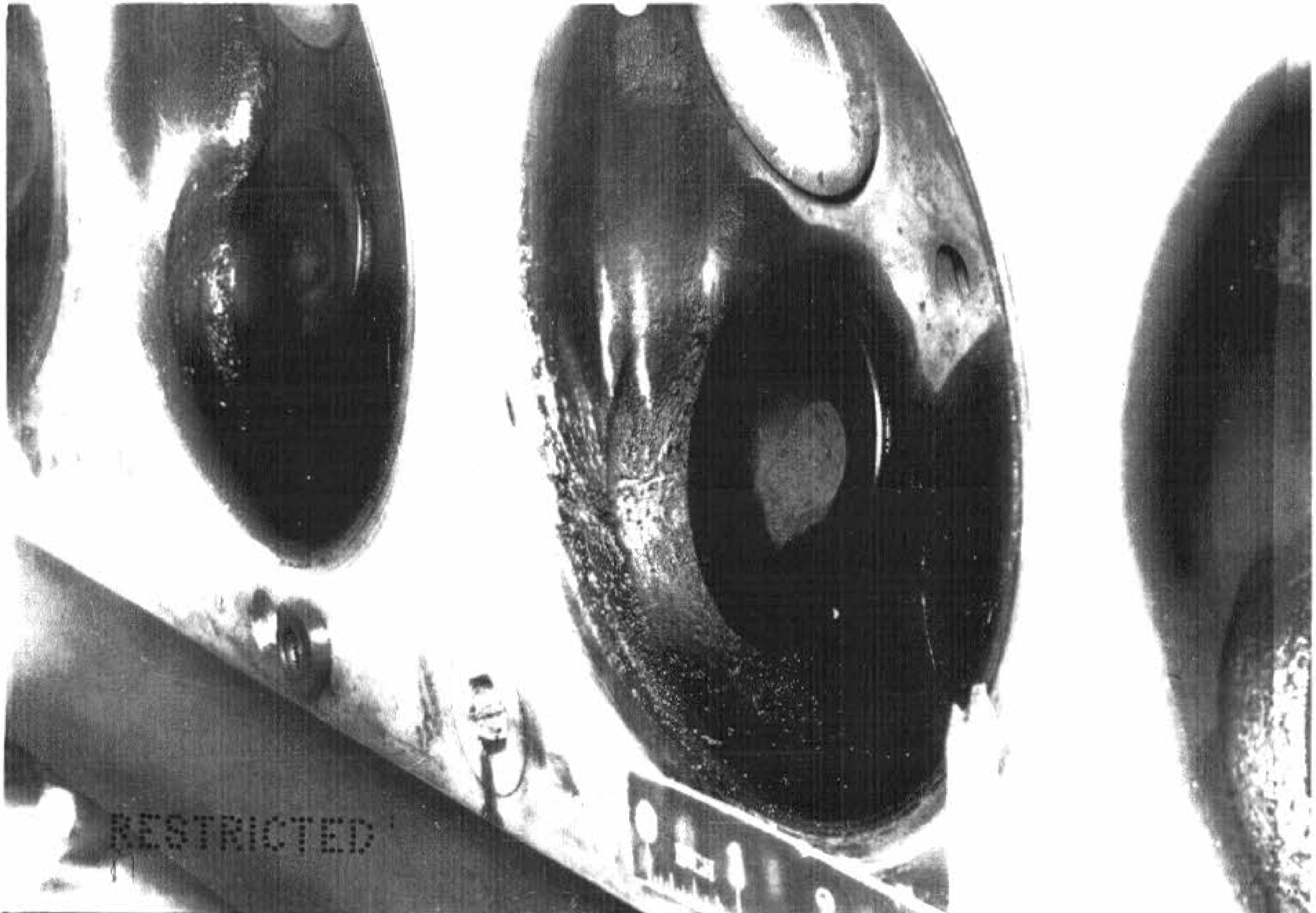
Right Cylinder Head, Ford Tank Engine, #1483, Medium Tank, M4A3, #2968. Engine hours: 108:50. Note condi-

APG Photograph 80088

April 7 1943

Combustion Chamber #3 Cylinder, right head, in vicinity of #1 intake valve, Engine #1483, Medium Tank, M4A3, #2968. Engine hours: 108:50

Note porosity of metal.



80088 4-7-43 ABERDEEN PROVING GROUND ORDNANCE DEPT.

Combustion Chamber #3 Cylinder, right head, in vicinity of #1 intake valve, Engine #1483, Medium Tank, M4A3,

APG Photograph 80782

April 9 1943

Project 4-28-1. No. 1 Piston R. B. (exhaust side) Ford Tank Engine, #1483, Medium Tank, M4A3, #2968. Engine hours: 108:50. Note erosion.

RESTRICTED

80782 4-9-43 ABERDEEN PROVING GROUND ORDNANCE DEPT.

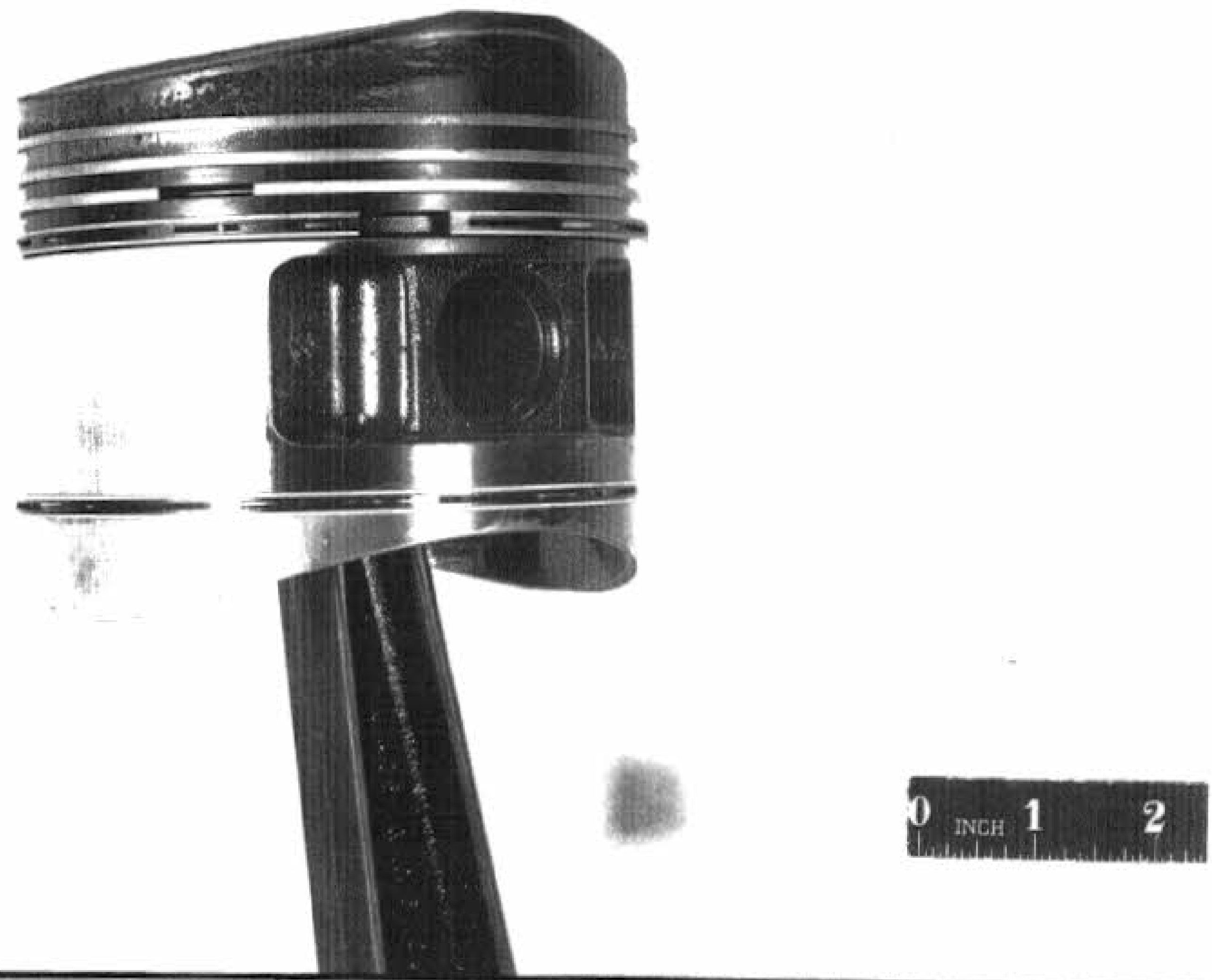
Project 4-28-1. No. 1 Piston R. B. (exhaust side) Ford Tank Engine, #1483, Medium Tank, M4A3, #2968. Engine hours: 108:50. Note erosion.

APG Photograph 80783

April 9 1943

Project 4-28-1. No. 3 Piston R.B. (exhaust side) Ford Tank Engine, #1483, Medium Tank, M4A3, #2968. Engine hours: 108:50. Note erosion.

RESTRICTED



80783 4-9-43 ABERDEEN PROVING GROUND ORDNANCE DEPT.

Project 4-28-1. No. 3 Piston R. B. (exhaust side) Ford Tank Engine, #1483, Medium Tank, M4A3, #2968. Engine hours: 108:50. Note erosion.

(5) Engine #645 — This engine operated for 456:55 hours without a major failure.

(6) Engine #715 — The crankshaft broke at #3 throw after 355:00 hours of engine operation. See APG. Photographs #79799, #80003, and #80003A.

(7) Engine #1483 — Broken piston rings and excessive cylinder bore wear after 108:50 hours. See APG. Photographs #80086 -#80088 inclusive, #80782, and #80783.

(8) Engine #1600 — This engine operated for 414:50 hours without a major failure.

The conculsions of Report No. #20-42 were as follow:

a. (1) The Ford Model GAA engine is a very satisfactory medium tank power plant.

b. (2) This engine is more accessible than any other medium tank power plant now in use; therefore, it is more easily serviced and maintained.

This report recommended that:

a. The Ford model GAA engine be approved for production as a power plant in the medium tank in such quantities as are deemed necessary to supply demands of the present and immediate future.

b. The necessary minor corrective modifications be placed on the production units as soon as possible.

c. Further development work be carried out on this engine with a view to increasing its mechanical reliability.

Following the above mentioned Aberdeen test the Tank Arsenal Proving Ground at Utica, Michigan conducted an endurance test on various modified Ford engines. This test was covered in "Endurance Test of Special Ford GAA Engines, Medium Tanks M4A3" (T.A.P.G. Reprt No. PG-60403.32, dated 29 June 1944)

Four production Ford tank engines previously tested revealed the life of standard exhaust valves, starters, generators, and exhaust manifolds to be deficient. The current test was undertaken with four Ford engines, incorporating changes designed to improve these items, together with changes and replacements of other standard items.

In order to obtain 400 hours of operation, the original mileage authorization was extended from 16,000 to 20,000 miles, as the average speed of the vehicles over the test course proved to be greater than anticipated.

The object of the test was to determine the durability of the engine components, and fuel and oil consumption characteristics of four (4) special Ford engines, in order to evaluate design changes in the engines.

The four special GAA Ford tank engines used for test had these features in common, which differed from standard production:

1. Hard cylinder bore sleeves, 42-46 Rockwell C.
2. Vertical main bearing studs.
3. "Cleveland" locked connecting rod bearings.
4. Shortedned exhaust valve guides.
5. Starter with new provisions for prevention of locking of Bendix pinion.

The test engines had these features, individually, which differed from standard production:

Test No. 1 --Engine No. 5500, M4A3 Medium Tank W-3,054,885

1. "Bright Ray" exhaust valves made by the Rich Manufacturing Company.
2. GAN oil pump with relief grooves.
3. Special #7171 Long clutch.
4. Sealed clutch housing.

Test No. 2 --Engine No. 5501 - Low Silhouette Engine, M4A3 Tank W-3,054,911

1. "Bright Ray" steel faced exhaust valves.
2. GAn oil pan with dual pump.
3. GAY Cylinder heads.
4. Horizontal carburetors.
5. Hydraulic governor.

Test No. 3 --Engine No. 5502, M4A3 Tank W-3, o54,926

1. Wilcox Rich stellite face, sodium cooled, exhaust valves.

2. GAN oil pan, and dual pump.

3. Special #7172 Long experimental clutch.

4. Sealed clutch housing.

5. Special spark advance governor.

Test No. 4 --Engine No. 5503, M4A3 Tank W-3,054,934

1. Wilcox Rich stellite face exhaust valves.

2. GAN oil pan, and dual pump.

3. Carburetor adapters with special Bound Brook bushings and Chicago Rawhide synthetic seals on the right side of throttle shafts.

4. King Seeley oil filter.

5. Governor unit with cast anchor arm for speed adjustments and spring.

Conclusions and Recommendations

Hard Cylinder Bore Sleeves, 42-46 Rc

The use of high hardness cylinder bore sleeves did not reduce cylinder bore wear as had been anticipated, and increased the overall oil consumption of these engines as compared with the previous test of four standard production engines. The straight face rings were comparatively slow seating as indicated by the oil consumption curves not reaching a minimun until late in the test. This trouble had been improved in later tests by using taper face rings.

Vertical Main Bearing Studs

"Cleveland" Clamped Connecting Rod Bearings

Shortened Exhaust Valve Guides

These items completed test satisfactorily and were recommended for use.

Starter with New Provisions for Prevention of Locking of Bendix Pinion

There were three (3) starter failures during test. Two of the failures were not changeable to starter anti-locking provisions, one being due to failure of the starter center bearing thrust washers, and the other caused by failure of the starter solenoid passing continuous current through the starter. In the third starter failure, the starter locked engaged at 2517 part miles. The saw-toothed anti-lock stop was improperly indexed on the shaft so the starter pinion did not make proper contact. Subsequent to this test, starters employing steeper stop nut saw teeth, a pinion of higher polar moment of inertia, and a stiffer anti-drift spring, were installed on test vehicles. These starters have operated satisfactorily to date and their use was recommended.

Exhaust Valves

The test was completed on all four engines without interruption for exhaust valve repair. Engine inspection at end of test revealed the sodium cooled stellite faced exhaust valves, and the stellite faced exhaust valves to be in better condition that the "Bright Ray" valves. The stellite faced exhaust valves were released for production during test, and the stellite faced sodium cooled exhaust valves at end of test.

GAN Oil Pumps and Installation

The twin oil pump GAN installations functioned satisfactorily throughout the test. On this basis, the use of the GAN oil pump installation was recommended. It was thought, however, that steps should be taken to prevent the cracking of the oil pan baffles, disintegration of the oil pump screen, and cracking of the oil pan flange as shown in the engine inspections.

The GAN oil pump with relief grooves completed test in good condition. The pump housing relief grooves were used to prevent trapping oil between the gear teeth. Their function was satisfactory and they were being used in the oil pumps of later series engines.

Clutches

The only clutch failure, a standard clutch on NO. 4 engine at 3594 test miles, was preceded by towing of another vehicle, and loss of free play, and so did not indicate any deficiency of the clutch. The other three clutches completed the test in good operating condition. On the basis of this test, the experimental clutches were recommended for use.

Sealed Clutch Housings

The interior of the clutch housings on No.1 and No. 3 test engines were not clean at end of test. All four of the louvered breather openings of the first housing were found to have been left unsealed. The interior of the housing, instead of being cleaner than standard assemblies, was fouled with dust, oil, grease, and gravel. The clutch, however, was in good operating condition. The interior of the second sealed housing at end of test was fouled with grease, oil, and oil soaked dust, but the clutch was in good operating condition. From the results of these tests, it was concluded that the sealed clutch housings offered no improvement over standard clutch housing regarding fouling of the clutch mechanism, and are not recommended for use.

Gay Cylinder Heads

The GAY cylinder heads on No. 2 test engine completed test in good condition. The left bank #2 and #3 cylinder head gasket and compression seal fairues at 2850 test miles were not considered to be chargeable to the cylinder head. The replacement head gasket and seals which were installed at the time of failure completed the test in good condition. On the basis of test, the use of this head was recommended.

Horizontal Carburetors (Low Silhouette Engine)

The No. 2 test engine as received had a flat spot on acceleration from idle similar to that encountered with insufficient accelerator pump action, but was attributed to the manifold distribution peculiar to this engine. Replacement of the standard coolant thermostat with a 155°F. opening thermostat improved the characteristic considerable but not to the point desired. As a result of this test, it was concluded that further development of the horizontal carburetion was desirable, and this work was undertaken by the engine and carburetor manufacturers.

Five times during test the horizontal carburetor linkage required repairs. This throttle linkage was unique and did not approximate either the standard GAA or GAY installations. Operation of the linkage was characterized by excessive accelerator pedal effort, binding, and wear of the linkage joints. Hardened linkage pins were used in the later repairs. As a result of this test, it was concluded that an improved line up of the linkage and the employment of hardened pins, and in some applications larger pins would be desirable. This has been done by the engine manufacturer or subsequent low silhouette engines.

The carburetors were removed once during test due to failure of the float bowl needle valves. Two of the four needle valves were unseated by dirt, and the bond of the synthetic needle face to the needle had failed. Improvement of the bond of the synthetic needle has been undertaken by the manufacturer. Unseating of the synthetic faced needle valves by dirt was characteristic of these valves. The dirt did not migrate into the float bowl as in the case of the metal face needle valve carburetors but tended to stick to the synthetic valve faces, causing a rich mixture and a smoky exhaust. It had been found that this condition could be remedied by cutting off the fuel flow to the idle jet with the fuel cut off solenoid until the engine starts to die, then releasing the cut off switch and accelerating the engine at no load to governed speed, the sudden increase of fuel flow over the synthetic needle valve being sufficient to wash it free of dirt particles.

Hydraulic Governor

The hydraulic governor became inoperative at 1729 test miles due to wear of the governor throttle linkage. The complete governor installation was replaced to repair the wear on the governor output shaft fulcrum where it took the governor linkage load. The governor unit was replaced due to hydraulic line replacement considerations at the time of output shaft removal. The governor was undamaged at removal and the replacement unit functioned satisfactorily for the remainder of test. From this it was concluded that the employment of a hardened bushing instead of needle bearings at the governor output shaft fulcrum was desirable. This change had been incorporated by the manufacturer in subsequent engines.

Special Spark Advance Governor

The special spark advance governor installed on engine No. 3 completed test satisfactorily and without incident. This governor gave a greater spark retard at low speeds than did the governor which was standard at the start of this test. The greater retard was employed to prevent detonation and reduce peak cylinder pressures at low speed wide open throttle operation. The fuel economy of the No. 3 engine was good and the special spark advance governor was released for production before the end of test.

Carburetor Adapters with Special Bound Brook Bushings and Chicago Rawhide Synthetic Seals

These special bushings and seals on No. 4 test engine were in excellent condition at end of test, and were released for production on final engine inspection. They were installed on the right end of the governor throttle shafts for the purpose of preventing the entrance of dust into the carburetor adapters. The use of the special bushings and seals on this engine tended to minimize the cylinder bore wear and make the right and left bank cylinder bore wear more nearly equal that was usual at this test mileage, in spite of evidence of dust leakage through the rear carburetor adapter gaskets. This leakage had been corrected by the use of a carburetor adapter gasket of greater crush.

King Seeley Oil Filter

The King Seeley oil filter installed on No. 4 test engine was found stalled at end of test and would not run on test installation in the engine manufacturer's laboratory. Due to failure of the unit, its use was not recommended.

An interesting 400 hours endurance test was conducted by G.M.P.G. on three Ford GAA tank engines, Serial No's. 5880, 7100, and

7101, to determine the qualities of special connecting rod bearings and various other special features. This test was covered in the report titled "Silver Clad Connecting Rod Bearings, Ford GAA Tank Engine" (G.M.P.G. Report no. PG-2.1299, dated 5 September 1944.)

The conclusions of this report were as follows:

1. The endurance qualities of the Silver Clad connecting rod bearings were superior to those of the standard bearings.

2. The Silver Clad Connecting Rod Bearings showed some failure in bond between the bearing metal and the backing.

3. The special Bohn Mfg. Metal used for main bearings showed no improvement over the standard bearings.

4. The endurance qualities of the special Hard Cylinder Liners were satisfactory and superior to those of the standard liners.

5. The use of the Sealed Power H.D. -22-x Piston Ring for the top oil ring improved oil consumption.

6. The Rich Stellite-Faced Exhaust Valves were not satisfactory since their endurance was only about 2500 miles.

7. The endurance of the Thompson sodium cooled and the Wilcox-Rich Stellite seated exhaust valves of over 4500 miles indicated that these valves were satisfactory.

8. The GAN oil pan with the Dual Oil Pump, the cylinder head gasket with the .012" grommets, the long dip sticks, and the Lock Type Oil Filler in the Left Camshaft Housing were satisfactory.

9. The operation of the engine revolution counter was not safisfactory because the oil seal to the counter housing does not function properly.

10. Several standard Ford GAA engine parts, namely the Cuno Oil Filter, the welded exhaust manifold assemblies, the push Rod of the Valve Mechanisms, and the spark plugs and spark plug wires, showed insufficient endurance mileage.

The recommendations of this report were:

1. The Silver Clad connecting rod bearings should be accepted for production since they had proved to be quite superior to current production.

2. The bond between the bearing metal and the backing of the Silver Clad connecting rod bearings should be improved.

3. The Hard Cylinder Liners, and the Sealed Power HD-22-x Top Oil Ring, should be adopted for production.

4. The results of further tests which were then in progress on Exhaust Valves for Ford GAA Engines should be studied before recommendations concerning the Exhaust Valves were made.

5. Action should be taken to improve the standard parts which were shown to have unsatisfactory endurance qualities.

Engines were then doing a fairly good job; however, occasionally a report would be received of an engine going out of time. With the increased frequency of this complaint, a thorough investigation of the timing system was made. Puzzling as it was, it was found that the quill, pet-named "dog bone," that served as a drive between the crankshaft and accessory drive, was twisting due to crankshaft torsional vibrations and loads applied thereto. the quill was immediately increased in diameter and an operation of shot-peening its outer skin was added.

The foregoing were only a few of the alterations and improvements made after the engine was in production. Many were minor in nature, yet important from the standpoint of ultimate engine performance and field maintenance.

Engine Rating

This engine produced 500 hp at 2600 rpm, with a torque of 1050 lb-ft at 2200 rpm. With a 7.5 to 1 compression ratio and a volumetric efficiency of 80 per cent, Ford Co. was able to obtain a brake mean effective pressure (bmep) rating of 142 lb at 2200 rpm. This is considered high in comparison to truck and passenger-car engines, which range from 100 to 120 bmep. Because of this high efficiency and high bmep, they also obtained a low specific fuel requirement of o.56 lb per bhp. All this was attributed to the efficient filling of the cylinders made possible by the intake system and valve arrangements. The thermodynamic process of the engine has been investigated by means of a temperature-entropy diagram in conjunction with indicator diagrams taken from the engine, which showed a satisfactory utilization of heat in the engine cylinders.

Much of the success of this engine can be attributed to the general arrangement of its installation in the tank hull. The accessibility for its maintenance was outstanding in that the component items of drives, fans, radiators, expansion tanks, etc., were strategically located, easy to get to for servicing.

As the war progressed changing our position from defensive to offensive, new designs of tanks were evolved. Tanks with lower silhouette, higher fire power, and greater thickness of armor were required at the battle front. This naturally necessitated that the engine be reduced in height, provisions made for various new power take-offs, arrangements and revisions of cylinder block to accommodate various types in installations such as the British Tank "Cromwell", the attaching of a 400-kw generator for the electric-drive tank, or the hysraulic torque converter ultimately used in the later days of tank production. It was truly a problem, for at one time Ford was providing seven different variations of this engine, for various designs of experimental tanks.

In spite of the numerous designs, an attempt was made whenever possible to standardize the engine, thus enabling interchangeability of parts subject to wear and burning, especially the power section, comprising cylinder block, cylinder heads, crankshafts, pistons, rods, valve assemblies, etc.

Twelve-Cylinder Design

At the beginning of the war it was an established fact that

15-20 hp per ton was necessary to propel a track-laying tank, 30 mph. As the war advanced tanks weighing 45-50 tons were developed, in which the power factor began to impinge on vehicle performance. Therefore it became apparent that a larger engine was necessary which could be produced within a short period. The natural thing to do was of course to add four cylinders to the eight, thus reverting back to the twelve-cylinder design.

The design was such that as many parts as possible of the power section were identical to the eight-cylinder engine. In cases where the design of the engines indicated a new part, every effort was made to place it in a similar arrangement with that of the eight-cylinder. Therefore a mechanic already familiar with the engine could easily tackle and repair a twelve-cylinder engine by recognizing the function of the component assemblies and knowing the method and procedure of tear down and reassembly. By the same token, the making of any necessary adjustments including the timing of the magnetos could also be done.

Provisions were incorporated in the new engine to enable optional arrangements of engine mountings. This was done to accommodate a variety of engine installations, whether they might be tank, truck, or tractor.

Electrical-starter problems were overcome by using two standard eight-cylinder starter motors, mounted one on each side of the engine. The principal reason for this arrangement was the inability to procure a larger starting motor that could be adapted to this engine. Should it have been possible to obtain a larger starter, the high stress concentration resulting at the starter and ring gears, would have been excessive for this installation. Other advantages were inadvertently realized; such as, utilizing an already in-production assembly, and in an emergency having the use of one starter, should the other one fail. Fifteen of these engines were built with more on order to be used in future developments of powering heavy vehicles.

While the various tests were being made on the Ford V-8 tank engine, development work on the Ford V-12 tank engine was initiated.

On 8 November 1944, a meeting was held with representatives of the Ordnance Department to discuss the development of a cooling system for the model GAC Ford V-12 tank engine. This engine was to be used in a new heavy tank (Model T29).

Preliminary work on this project was begun 10 November. Layouts were made showing the various arrangements of the component parts of the cooling system, such as the cooling fans, the radiators, the oil coolers etc. These drawings were studied and calculations were made in an effort to find an arrangement which represented the best possible compromise from the standpoint of military requirements, cooling, and available space.

The study included the consideration of using water-cooled oil coolers for the power train oil. Such a system would have great advantages--no external oil lines outside the power train, one set of (radiator) cores to dissipate the heat from both the engine cooling water and the power train oil, etc. However, calculations indicated that an appreciable saving in fan hp. consumption could be obtained by having the power train oil directly cooled by air in a set of oil coolers located behind the radiator cores for the engine cooling water. As low fan hp. consumption was one of the important requirements of the development of a suitable cooling system, the latter alternative was subsequently adopted by the Ordnance Department.

On 20 November another meeting was held with representatives of the Ordnance Department, and a general agreement regarding the arrangement of the component parts of the cooling system was reached. In this arrangement, each of two fans draws the air through an inlet grille and discharges it first through an 8" deep radiator core for the engine cooling water and then through a 3" deep core to cool the power train oil. The hot air then leaves the engine compartment through an outlet grille.

Due to the urgency of this development work, it was decided to carry on activities along two separate line simultaneously:

1 - To design and build a wooden mock-up of the right-hand half of the engine compartment. The object of this so-called "Cold Mock-up" was to furnish the test information required by the American Blower Corp. for the development of a cooling fan.

Chrysler Engineering Division CC-320

December 8 1944

Development of Engine Cooling System. Right front view of engine

#EX-1 As Received

Chrysler Engineering Division CC-321

December 8 1944

Development of Engine Cooling System. Left Rear View Of Engine #EX-1 As Received.

Chrysler Engineering Division CC-322

January 11 1945

Development Of Engine Cooling System. Engine Installed On Dynamometer for Power Test Before Installing HOT MOCK-UP - Right Rear View

Chrysler Engineering Division CC-323

January 11 1945

Development Of Engine Cooling System. Engine Installed On Dynamometer For Power Test Before Installing HOT MOCK-UP. Left Front View.

2 - To design and build a mock-up of the engine compartment which included the model GAC tank engine and the complete cooling system. In this "Hot Mock-up", the behavior of the cooling system could be studied under actual operating conditions.

Both of these mock-ups were erected and tested in the Dynamometer Laboratory.

This test at Chrysler was covered in the report titled "Cooling Characteristics of Ford V-12 Engine and Power Train" (Chrysler Report No T-60203.32, dated 24 October 1945).

The following descriptive data pertaining to the engine were obtained from the engine and from representatives of the Ford Motor Co.:

Model	GAC
Type	V-12
Number	EX-1 (painted on engine--no name plate)
Bore	5.4 in.
Stroke	6 in.
Displacement	1650 cu. in.
Compression Ratio	7.5:1
Spark Plugs	Champion C-88-s
Starters (2)	Autolite
Left	#MB04008 24v.
Right	Missing (Interference with bell housing prevented installation.

Chrysler Engineering Division CC-328

January 29 1945

Development Of Engine Cooling System. Fan No. 8084 Used In Cold

MOCK-UP

Chrysler Engineering Division CC-335

March 7 1945

Development Of Engine Cooling System. TEST SET-UP I-B; Engine Cover Around Flywheel End Of Engine In HOT MOCK-UP.

Carburetors (2)	Stromberg
	Model HD-5
Rear	Model HD-3
Fuel Pump	AC (No name plate)
Magnetos (2)	American-Bosch
Degassers (4)	12-24-V; Two on each carburetor
Oil Filter	Cuno Auto-klean
Number stamped on engine-Rear of Right Cyl. Head	HT-569L MT-1582 GAC 6050

The object of the test was to develop a cooling system for the model GAC engine. This was accomplished by means of:

1 - The construction of a so-called "Hot Mock-up" referred to as "Initial Design", or "TEST SET-UP 1". This set-up consisted of a sheet-metal mock-up of the engine compartment of the T29 Heavy Tank and included the model GAC engine and its experimental cooling system.

2 - Tests of this Hot Mock-up to determine the cooling characteristics of the experimental system.

3.- Revision of the mock-up to simulate the cooling conditions in the T32 Heavy Tank. This was designated "TEST SET-UP 11" and tests were performed similar to those of item 2.

The conclusions of this report were as follows:

1 - Satisfactory Cooling System Developed

A system was developed which met the specifications of the Ordnance Department fairly satisfactorily. When tested in TEST SET-UP 1I

Chrysler Engineering Division CC-338

April 18 1945

Development Of Engine Cooling System. TEST SET-UP I-B; Left Interior Of HOT MOCK-UP - Left Inlet Grille Removed.

Chrysler Engineering Division CC-340

April 18 1945

Development Of Engine Cooling System. TEST SET-UP I-B; Rear Interior Of HOT MOCK-UP - Top Deck Removed.

Chrysler Engineering Division CC-341

April 18 1945

Development Of Engine Cooling System. TEST SET-UP I; Left View Of Inlet Grilles And Air Duct Of HOT MOCK-UP.

Chrysler Engineering Division CC-345

April 18 1945

Development Of Engine Cooling System. TEST SET-UP I; HOT MOCK-UP

and Test Equipment.

Chrysler Engineering Division CC-356

July 19 1945

Development Of Engine Cooling System. TEST SET-UP II; Interior Of HOT MOCK-UP - Top Deck Removed - Rear View.

Chrysler Engineering Division CC-357

July 19 1945

Development Of Engine Cooling System. TEST SET-UP II; Right Front Interior Of HOT MOCK-UP - Top Deck Removed.

Chrysler Engineering Division CC-358

July 19 1945

Development Of Engine Cooling System. TEST SET-UP II; Left Interior Of HOT MOCK-UP - Side Panels Removed.

(which simulated conditions in the T32 Heavy Tank) this system provided a cooling performance of 93°F. (radiator top tank temp. minus air temp. at inlet grilles) at 2300 engine rpm., wide open throttle. The power consumption of the two fans amounted to 45 hp. at 2300 engine rpm., and 85 hp. would have been required at 2800 engine rpm. The Ordnance Department requested a cooling performance not to exceed 90°F. and a fan power consumption not to exceed 100 hp.

In brief, this system consisted of two cooling units, one on each side of the engine, and each unit in turn consisted of a fan assembly, a radiator, and an oil cooler. A 21-1/8" diameter, 6-blade, sheet-steel fan (See Photograph CC-368) forced air through the radiator and oil cooler which were placed in series. This fan was installed in a shroud containing guide vanes, and the complete fan assembly was developed by the American Blower Corp. in conjunction with tests made in the Cold Mock-up.

Each of the two radiators used to cool the engine water had an 8" deep fin-and-tube core and a frontal area of 553 sq. in. The two oil coolers were provided for cooling the power train oil, and each consisted of a 3" deep core having steel fins, copper tubes, and a frontal area of 504 sq. in.

2 - <u>Construction of Hot Mock-Up</u>

The sheet-metal mock-up of the T29 engine compartment is shown in Photograph CC-345. This apparatus was designated "TEST

Chrysler Engineering Division CC-359

July 19 1945

Development Of Engine Cooling System. TEST SET-UP II; Left Front Interior Of HOT MOCK-UP - Top Deck Removed.

Chrysler Engineering Division CC-366

September 20 1945

Development Of Engine Cooling System. Rear 3/4 View Of Fan Shroud & Guide Vane Assembly - Hot Mock-up (II) - Cold Mock-up (T-32).

SET-UP I" (or "Initial Design"). The set-up was of a preliminary nature because no drawings of the T29 tank were available when the design of the mock-up was started.

Two versions of SET-UP I were constructed, the principal difference being in the location of the "engine cover" which separated the inlet and outlet cooling air inside the engine compartment. The version having the engine cover around the water pump end (front end) of the engine is designated "Test SET-UP I-A"; "Test Set-up I-B had the engine cover around the flywheel (rear) end of the engine. Photographs CC-335 and CC-346 show details.

3- Revision of Hot Mock-Up

While tests of SET-UP I were in progress, the Design Department, working under a separate project, laid out a cooling system for the T32 Heavy Tank. This design was fundamentally the same as that tested in SET-UP I, but some changes had been necessary in fitting the cooling system into the tank.

The Hot Mock-UP was modified to simulate the cooling conditions of the T32 Heavy Tank, and this revision is designated "Test Set-Up II" (or "T32").

4- Cooling Performance

The following table is a brief summary of the results of cooling performance tests made with the Hot Mock-Up.

TEST SET-UP	I-A	I-B	II
	(Initial Design)	(Initial Design)	(T32)

Chrysler Engineering Division CC-367

September 20 1945

Development Of Engine Cooling System. Front View Of Fan Shroud & Guide Vane Assemble -Hot Mock-up (II) -Cold Mock-up (T-32).

Chrysler Engineering Division CC-368

September 20 1945

Development Of Engine Cooling System. Fan No. 8451 - Used In HOT Mock-Up (Test Set-up II) And Cold Mock-Up (T-32).

TEST GROUP	#1	#II	#15
ENGINE rpm.	2300	2300	2300
ENGINE LOAD	W.O.T.	W.O.T	W.O.T.
COOLING PERFORMANCE			
Ave. water temp. at rad. inlets minus ave. air temp. at inlet grilles ($\theta_1 - t_{1_a}$), $^\circ$F.	101.5*	103	93
ENGINE POWER OUTPUT TO DYNAMOMETER, Corr. bhp.	571	590	582

*No heat added to power train oil coolers.

Use of the average air temperature at the inlet grilles in computing cooling performance was agreed upon in consultation with Ordnance representatives.

5- Fan Performance

After the Hot Mock-Up tests were conpleted, test made in the Cold Mock-up showed that the fan assembly used in TEST SET-UP II delivered some 9% less airflow at 2300 engine rpm. than experimental fan No. 8311A which had been tested in the Cold Mock-up previously. Therefore, it was recommended that further cooling tests be made with the latter fan.

6- LOCATION OF ENGINE COVER

The cooling performance at 2300 engine rpm., wot., was not affected by the location of the engine cover. Tests of SET-UPs I-A and 1-B with no heat added to the power train oil resulted in identical average cooling performances.

7 - Position of Inlet Grilles

The "original position" of the inlet grilles in each test set-up was such that the tops of the bars pointed towards the front of the vehicle. During some tests, the grilles were reversed end for end so that the tops of the bars pointed rearward. Reversing the grilles had the effect of making the air temperatures around the engine more uniform. In general, these temperatures were increased, but the high temperature at the rear degasser was eliminated.

Reversing the grilles had no appreciable effect on cooling performance at 2300 engine rpm., wot. With TEST SET-UP II, an average value of 93° was obtained with the grilles in either position.

8 - Effect of Power Train Heat on Cooling Performance

Supplying heat to the power train oil coolers at the rate of about 8000 btu./min. caused the engine cooling performance to be from 1° to 5° poorer than for comparable tests with no heat added to the coolers.

9 - Bursting Speeds of Fans

One 20-blade cast aluminum fan of the type used in TEST SET-UP I was burst at 8800 rpm. No failures of the 6-blade sheet-steel fans used in SET-UP II were obtained, although two were spun at 8400 rpm.

This test was one of the last tests conducted, as cessation of hostilities curtailed additional development work on this engine.

Conclusion

In conclusion it was realized, that development and production programs where progress was made seemingly through a feat of magic such as this, were common throughout the entire country.

The Ford Motor Company attributed the successful program of producing 25,000 tank engines to the diligent co-operation of departments within the Ford sphere, together with cooperation received from other manufacturers, all striving for a common goal by producing in harmony, the requirements of the Army Ordnance.

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