E-28

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED

January 1946 as
Advance Restricted Report E5L18a

SINGLE-CYLINDER ENGINE TESTS OF POROUS CHROME-PLATED CYLINDER BARRELS WITH SPECIAL BORE COATINGS FOR RADIAL AIR-COOLED ENGINES

By Robert L. Johnson and Roy I. Anderson

Aircraft Engine Research Laboratory
Cleveland, Ohio

WASHINGTON

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

ADVANCE RESTRICTED REPORT

SINGLE-CYLINDER ENGINE TESTS OF POROUS CHROME-PLATED CYLINDER BARRELS WITH SPECIAL BORE COATINGS FOR RADIAL AIR-COOLED ENGINES

By Robert L. Johnson and Roy I. Anderson

SUMMARY

A series of single-cylinder engine tests was run to determine the effect on oil consumption and ring wear of special surface coatings in porous chrome-plated cylinder barrels for radial air-cooled engines. The coating materials were selected on the basis of bearing and lubrication properties and on the applicability of the materials to processing. This work was necessitated by the complications incurred in using standard flat-face compression rings in straight-bore porous chrome-plated cylinder barrels.

Straight-bore porous chrome-plated cylinder barrels coated with lead and silver overplates and similar barrels painted with colloidal graphite base paint were tested. Control tests were run with cylinders having no coating. A choke-bore porous chrome-plated cylinder barrel with a silver overplate was tested. Control tests with run with similar cylinders having no overplate.

Silver proved to be the most effective surface coating; it reduced the mean specific oil consumption and resulted in decreased ring wear. A coating of colloidal graphite base paint had about the same effect on the mean specific oil consumption and ring wear as the silver overplate; however, this coating did not remain in the pores on the thrust faces of the cylinder bore. Owing to a granular structure the lead plating was not of satisfactory quality and did not decrease oil consumption, although it did reduce ring wear. The lead apparently adversely affected the running-in properties of the assembly, as indicated by the exceptionally high initial oil consumption.

The effectiveness of silver as a means of providing a filled porosity was influenced by the catalytic action of the silver on the oxidation of lubricating oil, which resulted in very heavy deposits of lacquer, varnish, or both on the plated surface. These engine

deposits serve to fill the pores very well and satisfactorily adhered to the surface during engine operation. The silver, however, did not completely adhere to plateau surfaces at scattered locations in the cylinder tested.

INTRODUCTION

Previous testing by the NACA of porous chrome-plated cylinder barrels in radial air-cooled engines has shown that problems of ring wear and high specific oil consumption must be overcome before porous chrome-plated cylinders can be adapted for service use on engines having flat-face compression rings. The successful adaptation of porous chrome plating would be of value because it would facilitate the salvage of worn cylinders and would greatly reduce the spare-parts requirements by eliminating the need for oversize piston and ring assemblies.

As part of a program being conducted to determine means of improving the performance of radial air-cooled engines with porous chrome-plated cylinder barrels, a series of single-cylinder engine tests was run at the NACA Cleveland laboratory on front-row cylinders that were porous chrome plated and had additional special bore coatings. The object of these tests was to determine the effect of filling the porosity on specific oil consumption and to determine the most effective means of filling the pores. It was thought that by filling the pores less volume would be available as lubricating-oil reservoirs and consequently the oil control by the piston rings would be more positive, thereby resulting in decreased oil consumption.

The materials for the bore coatings were selected on the basis of bearing qualities or lubricating characteristics and on their applicability for processing. In accordance with these criteria, tests were run on straight-bore porous chrome-plated cylinders with overplates of lead and of silver as well as on a cylinder having a coating of baked colloidal graphite base paint. The effect of filling the pores was checked on a silver-overplated, porous chrome-plated cylinder with a choke-plated contour.

APPARATUS

The front-row cylinders used have a bore of $5\frac{1}{2}$ inches and were tested on a single-cylinder NACA universal test engine with a $5\frac{1}{2}$-inch stroke. The compression ratio for the assembly was 6.7. The tests were run with a standard ring assembly, which includes flat-face cast-iron compression rings, dual oil-control rings, and an oil-scraper ring.

Lubricating oil was supplied to the piston and the cylinder by means of crankshaft throw-off and four auxiliary oil jets; two jets were directed at the under side of the piston and two jets were directed at the barrel surface. The four jets had a total flow rate of approximately 5 pounds per minute. Oil consumption was measured with a standard NACA oil-weighing device as described in reference 1.

Fuel flow was measured with a calibrated rotameter and the quantity of combustion air was determined by means of a thin-plate orifice assembled in accordance with A.S.M.E. standards. The fuel was supplied to the manifold by constant injection with an altered manifold injection nozzle. Engine power was absorbed and measured with a cradled electric dynamometer.

The blow-by rate was determined by means of a positive-displacement gas meter. The crankcase pressure was manually maintained at 1/2 inch of water vacuum in order to keep the leakage into the crankcase constant.

The internal-surface projector shown in figure 1 and described in reference 2 was used to inspect and photograph all cylinder surfaces before and after test.

TEST PROCEDURE

The piston rings used in these eight tests were inspected for light-tightness as specified in Aeronautical Material Specification 7310, issued November 1, 1941. Measurements were made of free gap, compressed gap, oil-ring bearing-face width, and diametral tension before and after testing. Compressed gap was measured in a standard ring gage of nominal diameter and ring-face width was determined with a calibrated microscope. Diametral tension was measured by determining the force applied on a diameter 90° from the gap necessary to close the ring to its installation compressed gap. The rings were weighed before and after test with an analytical balance. Unit wall pressure was computed for the oil-control rings by the same method used in reference 2.

All cylinders were run-in before testing; a summary of the run-in schedule is given in table 1. The following conditions were held constant for the eight single-cylinder tests conducted:

Engine speed, rpm	2400
Brake mean effective pressure, pounds per square inch	192
Spark timing, degrees B.T.C.	25
Fuel-air ratio	0.095

Maximum temperatures, °F:
  Rear spark-plug bushing 420
  Center of barrel, downstream 325
Oil-in temperature, °F 180

The oil used was Navy symbol No. 1120; the fuel used was AN-F-28, Amendment-2.

The cylinders used in tests 1, 2, 3, and 5 were plated in June 1943 and the cylinders used in tests 4, 6, 7, and 8 were plated in December 1943. The specifications used in porous chrome plating these cylinders are essentially the same as those given in reference 2 except that for the cylinders of tests 4, 6, 7, and 8, closer limits were held on plating conditions.

After the cylinders were chrome-plated, they were rough-honed with B-320 B-12 stones and finish-honed with B-600 B-10 stones. These honing stones have refined aluminum oxide as the abrasive and have a bakelite (resinous) bond. All cylinders were cleaned with a trichloroethylene spray using compressed air at a pressure of 100 pounds per square inch. The nozzle was manually directed in cleaning the cylinders used in tests 1, 2, 3, and 5 and mechanically directed in cleaning the cylinders used for tests 4, 6, 7, and 8. Three complete passes of the cylinder were made in each case. The surface condition of each barrel was examined before and after test with the internal-surface projector.

The cylinder barrels used in tests 1 and 2 had straight bores. These tests were run for comparison with tests 3, 4, and 5 and were also reported as control tests in reference 2.

Test 3 was run with a straight-bore cylinder barrel having a lead overplate. The cylinder-bore surface was prepared for lead plating by successive treatments of scrubbing with pumice, dipping in dilute sulfuric acid, and rinsing in cold water. The plating bath was a lead sulphamate solution at room temperature having a hydrogen-ion concentration of 1.5. The cylinder was plated for 2 minutes with a current density of 40 amperes per square foot to obtain the calculated plate thickness of 0.0002 inch. The anode consisted of a lead strip inside the cylinder. No special racking was necessary.

The cylinder used in test 4 was a straight-bore cylinder barrel coated with a colloidal graphite base paint. The paint consisted of a colloidal graphite base in a vegetable binder with a trace of phosphoric acid. After the cylinder was painted, it was baked in an oven for 30 minutes at an actual cylinder temperature of 500° F.

The cylinder used in test 5 was a straight-bore cylinder barrel with a silver overplate. The cleaning of the porous chrome surface before silver plating consisted of a vapor degrease, a rinse, a second vapor degrease, and another rinse in cold running water. This procedure was followed by a dip in hot caustic soda at 160° to 180° F and another rinse in cold running water. The plating procedure included a silver strike followed by plating in a silver cyanide solution. The current density was 3 amperes per square foot; the time required to plate a calculated thickness of 0.0003 inch was 30 minutes. The anode was a $1\frac{1}{2}$-inch diameter cast-silver rod.

Tests 6 and 7 were run with choke-bore cylinders for comparison with test 8. These tests are completely described and discussed in reference 2. The choke was plated into the cylinders, which were ground, honed, or both to a straight bore in preparation for plating.

Test 8 was run with a choke-bore cylinder having a silver overplate. The silver plating was done using the same procedure as for the cylinder used in test 5. This test was run to check the effect of filling the pores in different types of cylinder.

RESULTS AND DISCUSSION

A summary of the more important data obtained from these tests is given in table 2.

A complete discussion of the data from the tests of straight-bore and choke-bore cylinders without special bore coatings (tests 1, 2, 6, and 7) is given in reference 2. In the present report, these tests are presented as control tests for comparison with the tests of coated barrels. The control-test data serve to indicate, to some extent, the range of reproducibility that might be expected in this series of tests.

Specific Oil Consumption

The results of the tests (figs. 2 and 3) show that when the porosity was effectively filled, the mean specific oil consumption was reduced approximately 15 percent. The lead overplate did not effectively fill the porosity and did not remain on the surface during engine operation; consequently, as figure 2 shows, there was no decrease in the mean specific oil consumption resulting from this coating. The colloidal graphite base paint remained in the pores sufficiently long to have a desirable effect; the specific oil consumption remained constant at the reduced value during the 10-hour test period. The silver overplate on both straight-bore and choke-bore cylinders had an appreciable effect on the specific oil consumption (figs. 2 and 3). The mean values of specific oil consumption for the test of the colloidal graphite base paint coating and the test of a silver overplate on straight-bore cylinders were the same. The effect of the silver overplate on specific oil consumption is believed to be more desirable than the effect of the other coatings.

Ring Wear

All the rings were in very good condition after testing. Figure 4 shows the condition of a representative ring assembly after test. In no case were the ring-wear values given in figure 5 considered to be excessive. It should be noted, however, that the ring wear was lower in uncoated barrels having choke bores than in the straight-bore barrels. This condition is thought to be mainly the result of both the improved method previously described of cleaning honing debris from the pores and the geometry of the surfaces at operating temperatures. In every application, the use of a coating resulted in reduced ring wear (fig. 5) as compared with the control tests. The reduction in ring wear was expected because the coating materials were originally selected on the basis of their good bearing or lubricating properties.

Cylinder-Barrel Wear

Although it was impossible to evaluate the actual cylinder wear because of the coatings and heavy engine deposits, wear in the cylinder barrels was considered to be very slight in every test. The dial-type gage used to measure cylinder wear is accurate to 0.0002 inch but will not give dependable wear measurements in cylinders from tests of this type even when used in the most careful manner possible.

A comparison of photographs of the same surface area taken before and after test showed changes in pore characteristics resulting from engine operation. The changes in pore characteristics observed give an indication of relative wear. A comparison of figures 6, 7, and 8 shows the changes that took place on a typical surface area after silver plating and after running. The wear is considered to be negligible in this area because a considerable amount of silver can be seen on the plateaus after test. (See fig. 8.) Figure 9 shows the general appearance of the silver-coated bore after test 8; the apparently unusual wear marks on this bore are merely variations in the amount of lacquer, varnish, or both deposited, as well as areas in which the silver did not completely adhere. The irregularity of the appearance of the bore shown in figure 9 does not indicate harmful operating characteristics. This observation is substantiated by figure 10, which shows the piston assembly run in test 8; the assembly is considered to be in very good condition.

Effectiveness of Coatings as Surface-Bearing and Lubricating Materials

In the consideration of the effectiveness of the coatings as surface-bearing and lubricating materials, several factors are of importance: adhesion of the coating to the barrel surface; the flow pressure of the material; frictional characteristics of the material; and, in the case of the nonmetallic coating, the ability of the material to serve as a lubricant.

The lead overplate was a granular deposit that did not adhere to the chrome throughout the test; the high initial oil consumption (fig. 2) indicates, however, that the lead adversely affected the running-in properties of the assembly. It is probable that the low flow pressure of the lead enabled it to be continually worked or smeared on the surface of apparent slider contact, thus reducing the abrading of the rings to such an extent that the run-in properties were adversely affected. Because the poor adherence may have been due to the undesirable characteristics of the lead plating, the data obtained from test 3 should not be considered as conclusive.

The use of colloidal graphite in aircraft-engine lubrication has been a controversial subject for some time although it is well known that graphite is a good lubricant. It was thought that the colloidal graphite base paint coating would provide effective additional cylinder lubrication as well as a possible means of filling the pores in the chrome plate. The low ring wear encountered in test 4 (fig. 5) might be attributed to the additional lubrication supplied by the coating. The piston from this assembly was in better condition than any piston from the other tests.

Silver overplate had better adherence to the chrome surfaces than any other coating material tested and consequently the effects of the silver coatings as a bearing material were the easiest to determine. The silver overplate in the straight-bore barrel adhered to the chrome better than the silver overplate in the choke-bore barrel. The adherence of the silver to the chrome may, however, have been influenced by the heating of the straight-bore cylinder in a furnace at a temperature of 350° F for 1 hour, which was done to replace a valve guide before testing. Treating silver in this manner will anneal it to a much less brittle condition and make it more desirable for use as a bearing surface. The silver had a sufficiently high flow pressure or hardness so that this coating did not have any apparent adverse effect on the run-in properties of the piston rings. Although it could not be accurately determined with the test equipment used, it is possible that, inasmuch as the coefficient of friction of silver against iron is the lowest found for any metal combination (reference 3), engine friction may be reduced somewhat by the use of a silver overplate as a bearing material on the cylinder bore. The possibility of decreased engine friction is also indicated by the reduced ring wear obtained in the tests of silver overplate. (See fig. 5.)

Effectiveness of Coatings in Providing Filled Porosity

Lead did not provide a satisfactory material for filling the porosity in these tests because of its poor adherence to the chrome plate.

Colloidal graphite base paint did not remain in the porosity on the thrust faces of the cylinder bore, but the porosity on the nonthrust faces was still effectively filled after test. It is estimated that approximately 60 percent of the volume provided by the pores remained filled after test. Because the amount of surface-relief filling decreased during the engine test, it is possible that in continued operation this trend may continue to such an extent that the specific oil consumption would increase. The painted coating on the bore cannot be expected to remain on the surface of the plateaus during engine operation. In the area of ring travel, all the coating was worn off the plateaus but it was noticed that these plateaus had an unusual surface discoloration. This discoloration may have been caused by a chemical reaction of the phosphoric acid in the binder with the chrome at the high baking temperature of the coating.

None of the coatings tested completely filled the pores in the chrome plate; however, silver provided an effective means of filling the porosity (fig. 11) because of its catalytic effect on the oxidation of lubricating oil (reference 4). This catalytic action is believed to be the cause of the very heavy coatings of lacquer, varnish, or both noted on the surfaces of the silver-overplated cylinders after engine operation. Catalysis is probably aided by a number of conditions encountered with this application, such as the high operating temperatures of the surface, the high ratio of surface area of silver plate to lubricating-oil volume, and the fine wear particles of abraded silver that undoubtedly were present. The material deposited on these cylinder bores after test effectively filled the porosity in the chrome plate.

Effect of the Coatings on the Engine

None of the coating materials had any apparent adverse effects on the engine; however, this condition may not be true in full-scale engine tests because of the greater quantity of coating material. Although the lead overplate did not affect the test engine to any noticeable extent, engine deposits that were slightly heavier than those in the control tests were found on the cylinder bore. It should be noted that lead also has a catalytic effect on the oxidation of lubricating oil. The colloidal graphite base-paint material was originally deposited in a fairly heavy coating on the bore but after test no unusual accumulation of material was found in the oil filters or in the crankcase. In spite of the very marked catalytic effect of the silver on the oxidation of lubricating oil, no excessive engine deposits were noted in any part of the engine other than the cylinder. The processing of silver-overplated cylinders must be handled very carefully in order to obtain satisfactory adhesion of the silver to the chrome. If the plate bond of the silver to the chrome is not good, chips of the silver plate might possibly have a harmful effect on bearing surfaces in the engine.

Evaluation of Performance of Coatings

An evaluation of the performance characteristics of the various bore coatings indicates that silver overplating was the most satisfactory type of coating tested. The silver had good adhesion to the porous chrome plate in these applications, was a good bearing material, and provided a good means of filling the porosity. It was not anticipated, however, that the coatings would completely adhere to the plateau surfaces during engine operation. Silver particles were flaked or abraded from plateau surfaces at scattered locations in the cylinders tested. The surface relief was filled by silver worked from the surface as well as by the silver originally plated and by the products of lubricating-oil oxidation. Because the effectiveness of the silver overplate in providing a filled porosity was largely the result of the accelerated engine deposition caused by the catalytic effect of silver on the oxidation of lubricating oil, less heavy coatings may be equally as effective in causing the pores to be filled as the thicker coatings. Because experience has indicated that the adhesion of very thin silver plates is more satisfactory than thicker plates, it is desirable to utilize this factor if possible.

These tests indicate that the function of the pores as surface reservoirs for lubricating oil is not the only factor that determines whether porous chrome plate on cylinder bores will perform satisfactorily. Filling the porosity effectively reduced the volume of surface reservoirs to such an extent that the pore area provided by this reduced volume was considerably less than the area indicated by previous unreported tests as the minimum surface relief that will allow successful operation.

SUMMARY OF RESULTS

Analysis of the data from single-cylinder engine tests of porous chrome-plated air-cooled cylinder barrels having special bore coatings that were run for 10 hours at an engine speed of 2400 rpm and a brake mean effective pressure of 192 pounds per square inch gave the following results:

1. The mean specific oil consumption was appreciably reduced in porous chrome-plated cylinder barrels having the porosity filled or partly filled by colloidal graphite or silver.

2. Silver overplate provided the most effective means investigated for filling the porosity, possibly because of the catalytic effect of the silver on the oxidation of lubricating oil. It is possible that a much thinner coating of silver would be equally as effective as the 0.0003-inch coatings tested. Silver remained in the pores but did not completely adhere to plateau surfaces at scattered locations in the cylinders tested.

3. Colloidal graphite base paint did not completely adhere in the pores during engine operation.

4. Silver overplate and other bore coatings tested slightly reduced ring wear when applied to the porous chrome-plated cylinder barrels.

Aircraft Engine Research Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio,

REFERENCES

1. Koffel, William K., and Biermann, Arnold E.: A Unit Laboratory Engine Oil System Providing for a Remote Indication of Oil Flow and Oil Consumption Together with Blow-By Measurement. NACA TN No. 952, 1944.

2. Johnson, Robert L., and Swikert, Max: Single-Cylinder Oil-Control Tests of Porous Chrome-Plated Cylinder Barrels for Radial Air-Cooled Engines. NACA ARR No. E5L18, 1945.

3. Hoyt, Samuel L.: Metals and Alloys Data Book. Reinhold Pub. Corp., 1943, p. 281.

4. Downing, B. F., Holbrook, G. E., and Fuller, J. H.: Effect of Engine Metals on the Deterioration of Motor Oil. Oil & Gas Jour., vol. 38, no. 5, June 15, 1939, pp. 70-75.

TABLE 1. - RUN-IN CONDITIONS AND SCHEDULE

[Oil, Navy symbol No. 1120; fuel, AN-F-28, Amendment-2; spark timing, 25° B.T.C.; fuel-air ratio, 0.095; maximum temperatures: rear spark-plug bushing, 420° F; center of barrel, downstream, 325° F; oil-in temperature, 180° F]

Period	Run-in time[1] (min)	Engine speed (rpm)	Brake mean effective pressure (lb/sq in.)	Brake horse-power
1	60	1200	48	10
2	60	1300	56	12
3	30	1400	68	16
4	30	1600	85	22
5	30	1800	109	32
6	60	2000	135	45
7	135	2200	162	59
8	30	2300	178	68
9	10	2400	192	76

[1]Total run-in time, 7 hours 25 minutes.

National Advisory Committee
for Aeronautics

TABLE 2. - SINGLE-CYLINDER ENGINE TESTS OF POROUS CHROME-PLATED CYLINDER BARRELS WITH SPECIAL BORE COATINGS FOR RADIAL AIR-COOLED ENGINES

[Oil, Navy symbol No. 1120; fuel, AN-F-28, Amendment-2; engine speed, 2400 rpm; brake mean effective pressure, 192 lb/sq in.; friction mean effective pressure, 16 to 20 lb/sq in.; fuel-air ratio, 0.095; spark timing, 25° B.T.C.; maximum temperatures: rear spark-plug bushing, 420° F; center of barrel, downstream, 325° F; oil-in temperatures, 180° F]

Type of cylinder investigated / Test results	Straight bore						Choke bore		
	No coating		Lead coating, 0.0002-inch overplate	Colloidal graphite base-paint coating	Silver coating, 0.0003-inch overplate	No coating		Silver coating, 0.0003-inch overplate
Test number	1	2	3	4	5	6	7	8
NACA reference test number	2	8	3	12	16	4	5	14
Duration of test, hr	10	10	10	10	10	10	10	10
Crankcase oil flow, lb/min	20	22	18	21	20	21	21	----------
Mean specific oil consumption, lb/bhp-hr	0.016	0.013	0.018	0.012	0.012	0.008	0.009	0.007
Average blow-by (uncorrected), cu ft/min	0.8	0.8	0.7	0.8	0.7	0.6	0.7	0.6
Ring weight loss, gram:								
1	0.087	0.101	0.061	0.082	0.088	0.074	0.088	0.054
2	0.076	0.106	0.053	0.028	0.037	0.054	0.062	0.029
3	0.059	0.085	0.050	0.022	0.032	0.043	0.048	0.023
4	0.049	0.060	0.036	0.018	0.025	0.036	0.039	0.017
5	0.043	0.054	0.063	0.016	0.013	0.030	0.043	0.018
6	0.042	0.041	0.019	0.008	0.021	0.023	0.025	0.016
Total compression-ring weight loss, gram	0.222	0.292	0.164	0.132	0.157	0.171	0.198	0.106
Total oil-ring weight loss, gram	0.134	0.155	0.118	0.042	0.059	0.089	0.107	0.051
Total ring weight loss, gram	0.356	0.447	0.282	0.174	0.216	0.260	0.305	0.157
Initial unit wall pressure for oil ring, lb/sq in.								
Ring 4	28	24	30	31	45	29	36	28
Ring 5	36	22	38	29	42	26	28	38
Ring 6	40	28	36	41	28	28	39	33

National Advisory Committee for Aeronautics

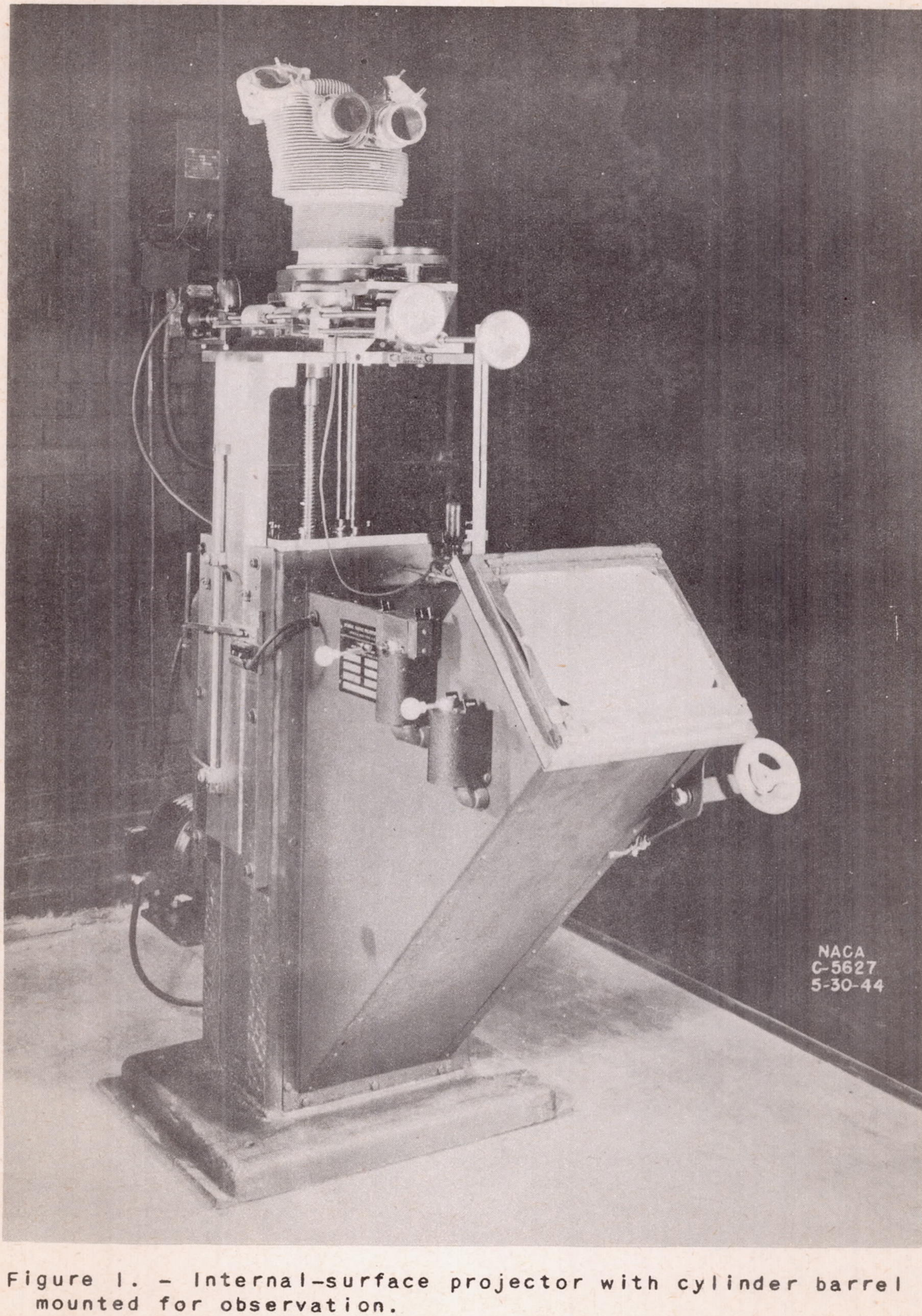

Figure 1. - Internal-surface projector with cylinder barrel mounted for observation.

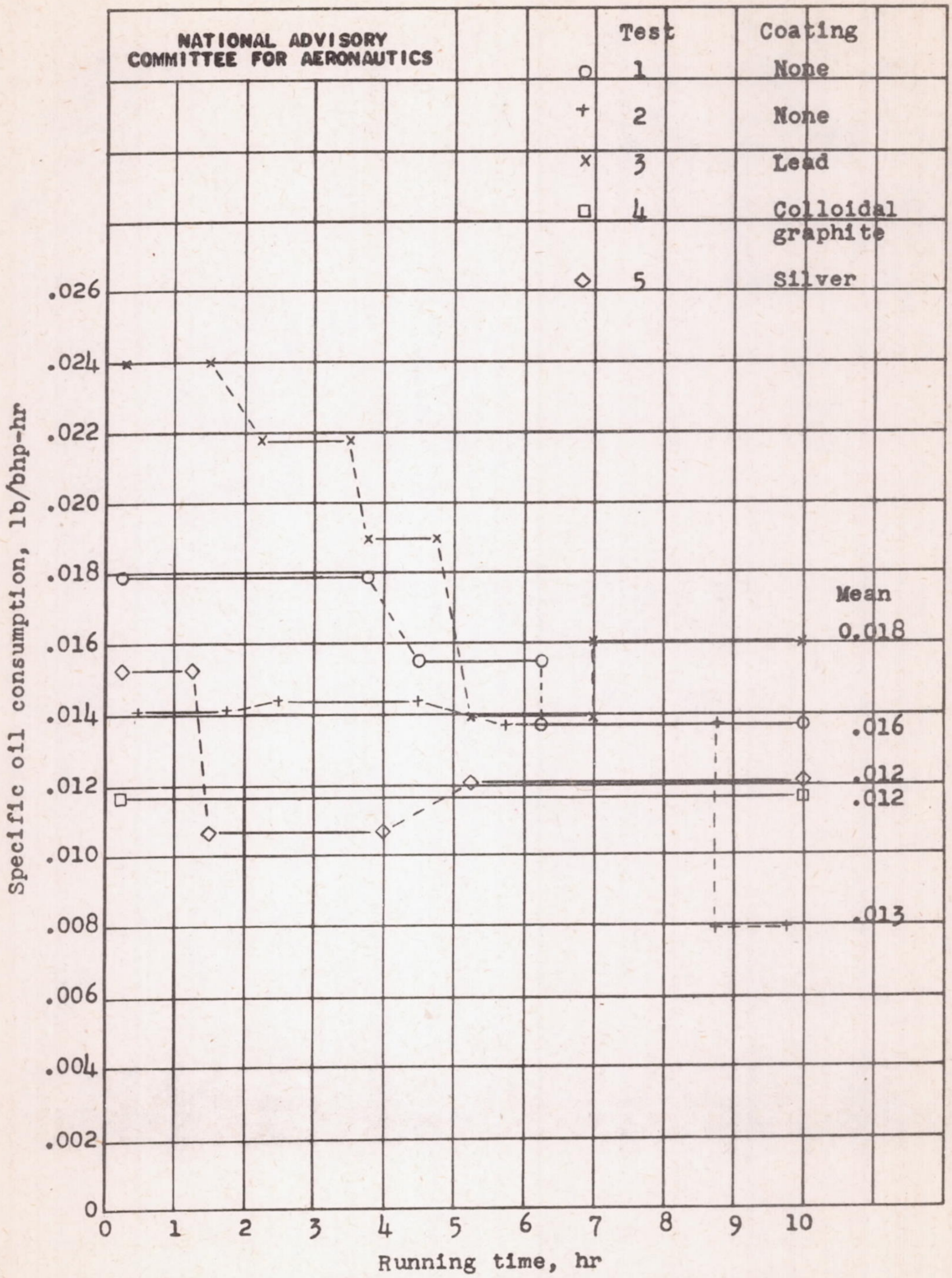

Figure 2. - Specific oil consumption for straight-bore chrome-plated cylinders with coated and uncoated cylinder surfaces. Engine speed, 2400 rpm; brake mean effective pressure, 192 pounds per square inch.

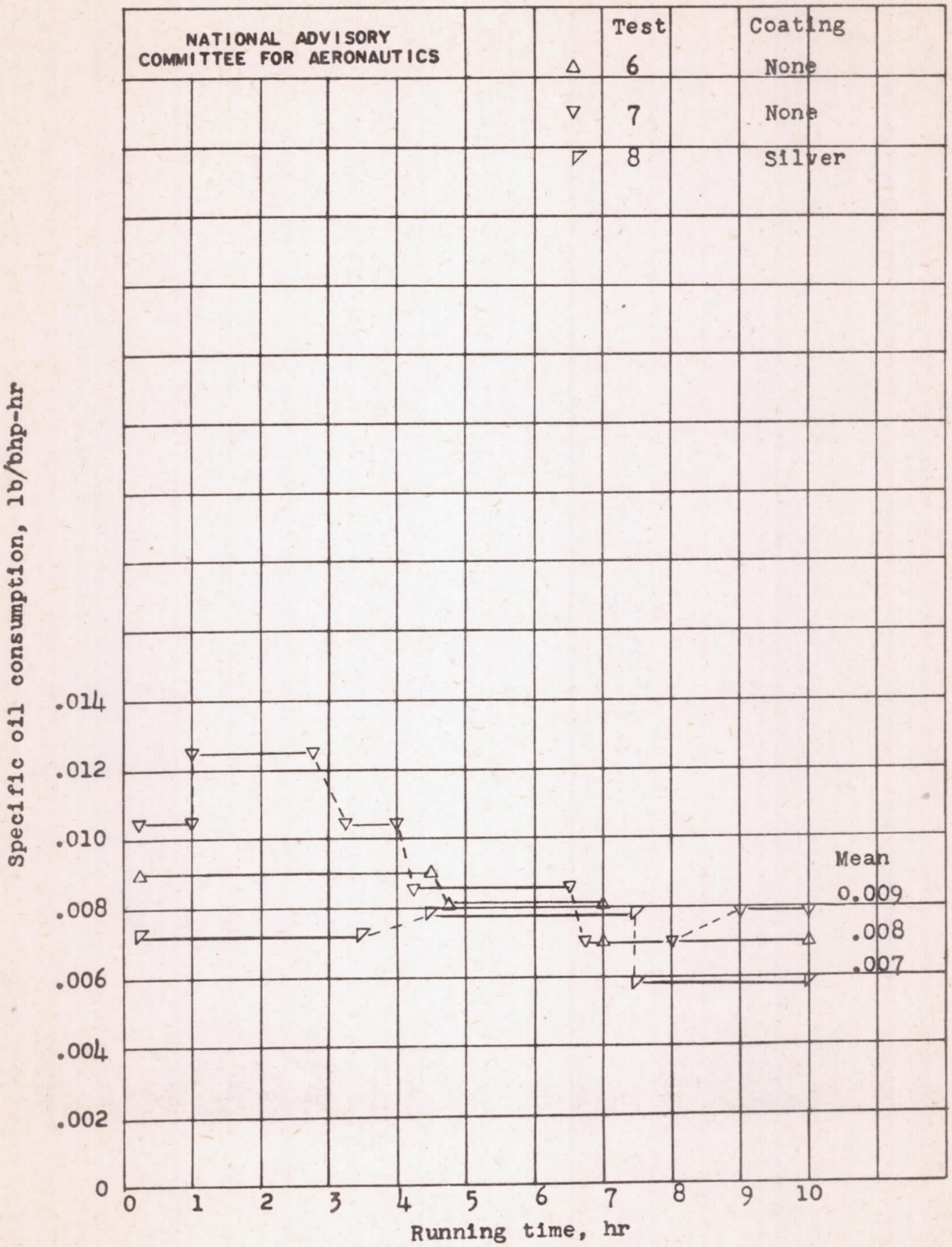

Figure 3. - Specific oil consumption for choke-bore chrome-plated cylinders with and without a silver overplate. Engine speed 2400 rpm; brake mean effective pressure, 192 pounds per square inch.

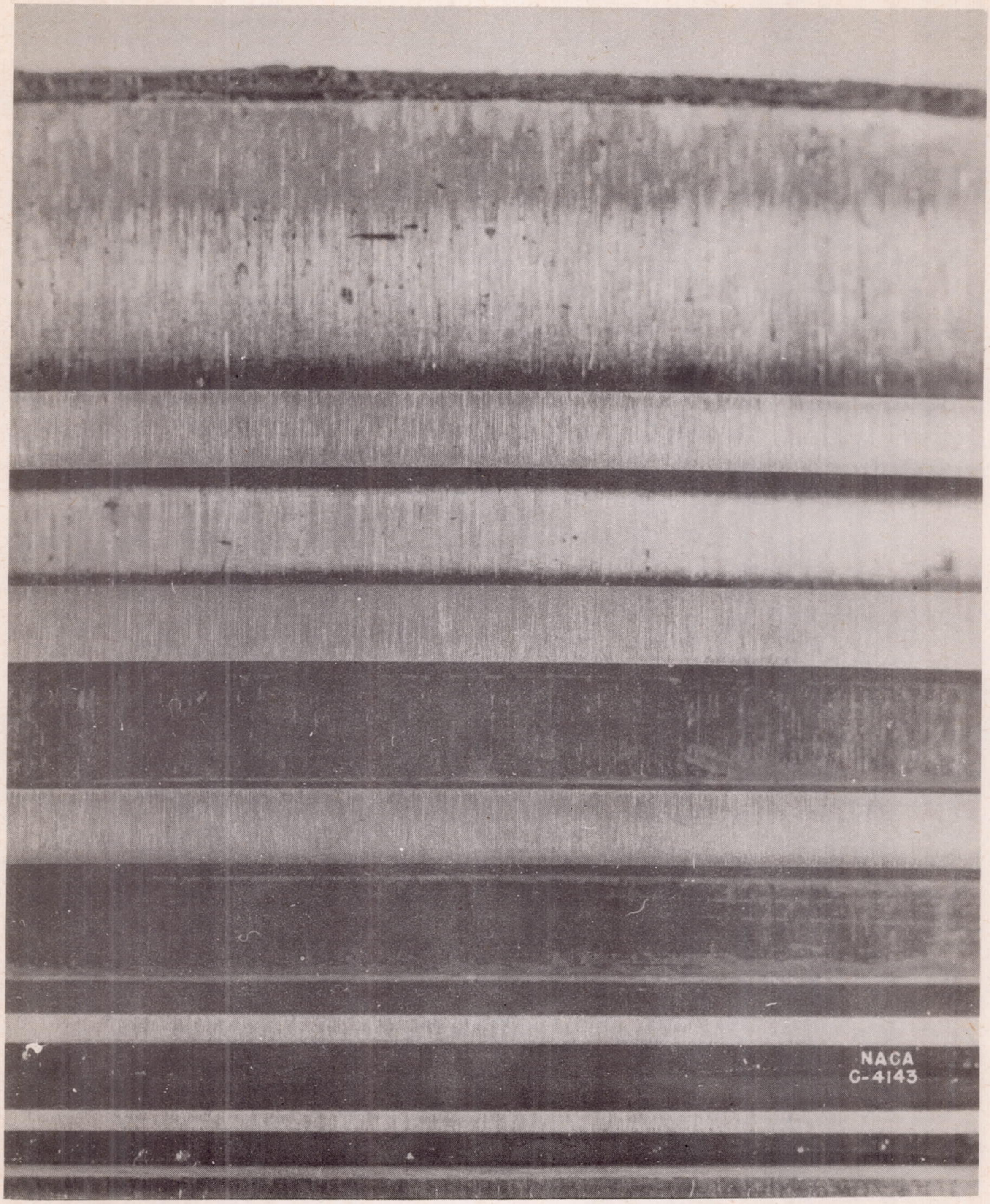

Figure 4. - Surfaces of top five rings, 180° from the gaps, after operation in a choke-bore porous chrome-plates cylinder barrel with a silver overplate. Condition after test 8.

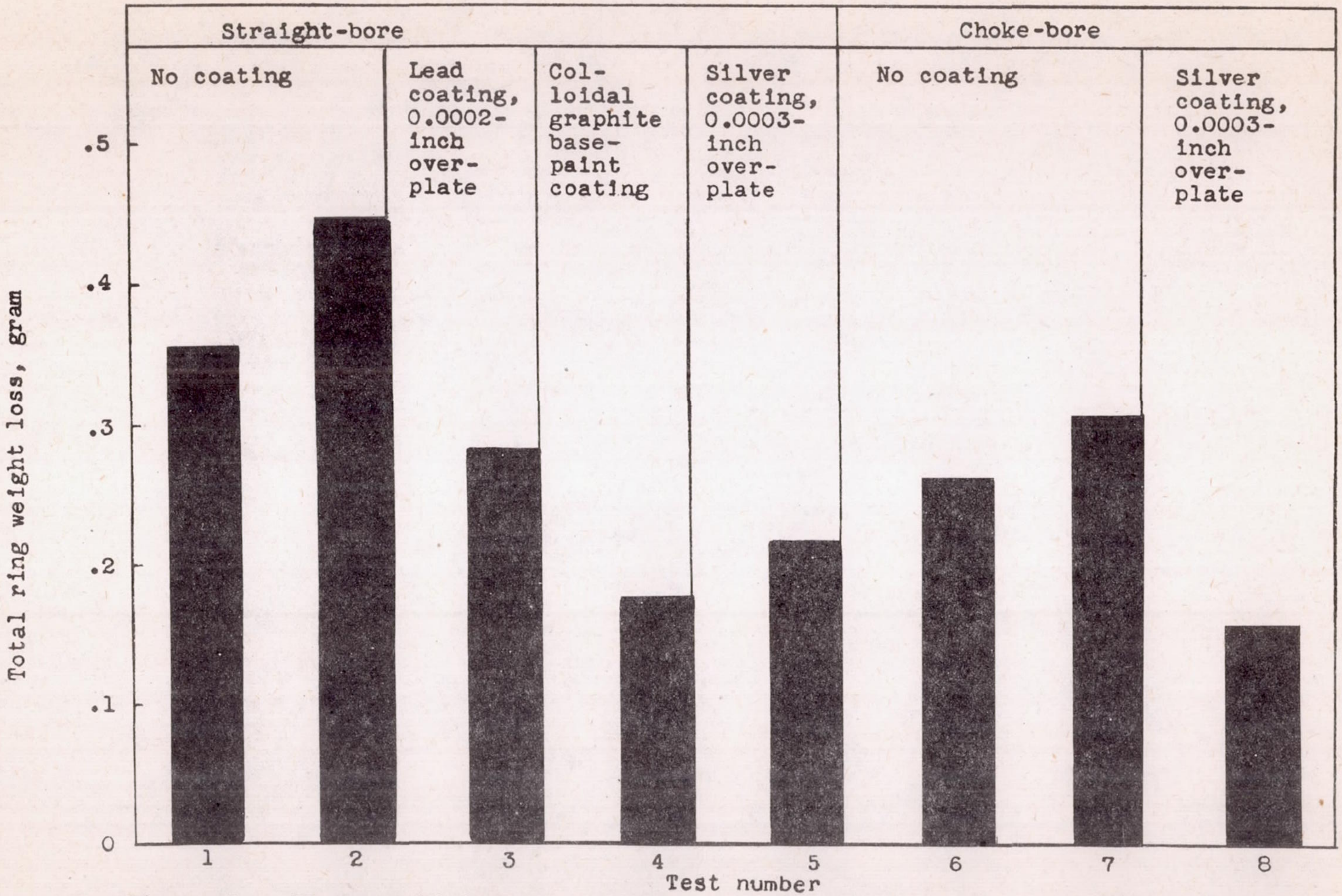

Figure 5. - Ring weight loss in straight- and choke-bore porous chrome-plated cylinder barrels with different barrel coatings. Engine speed, 2400 rpm; brake mean effective pressure, 192 pounds per square inch.

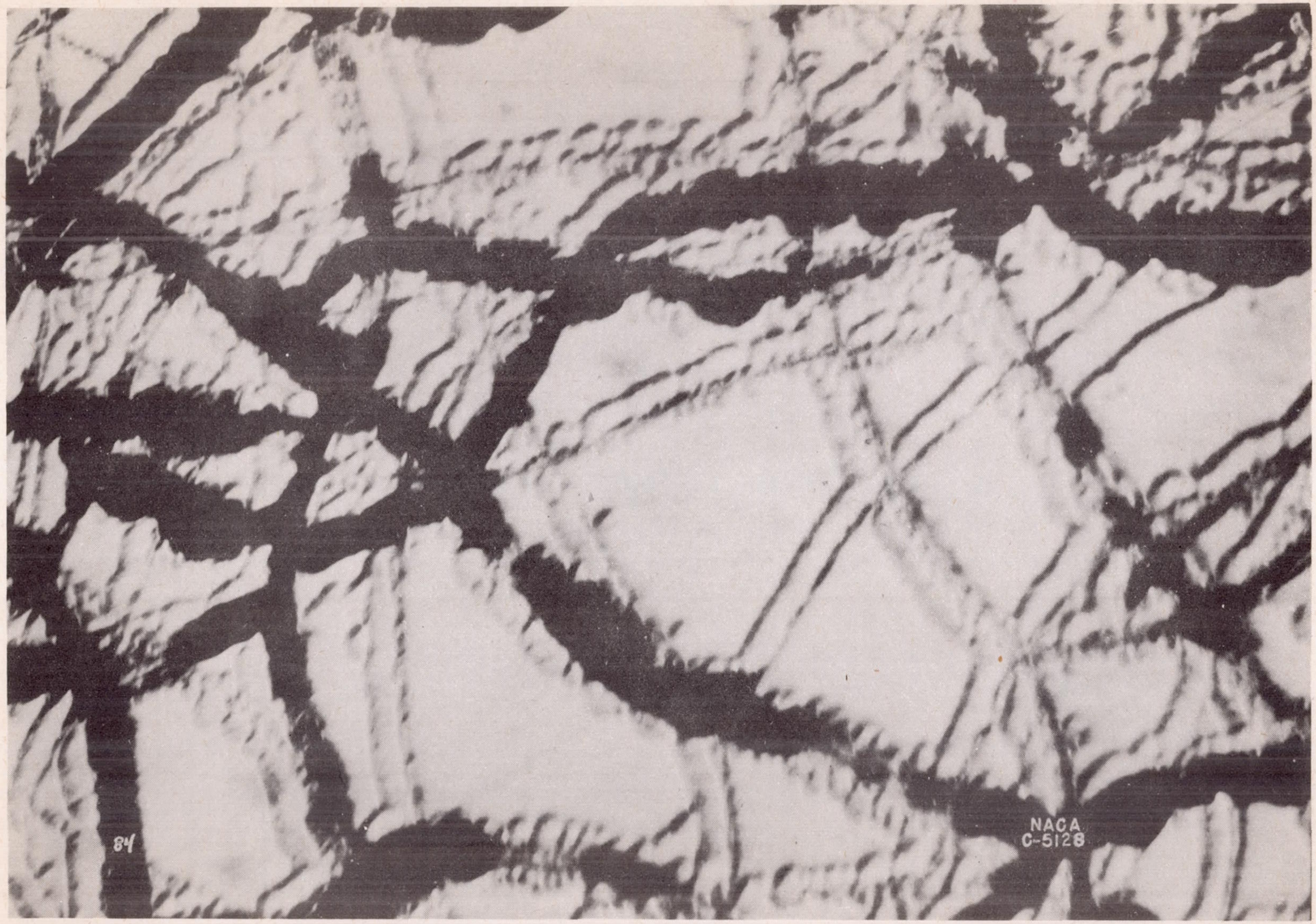

Figure 6. - Photomicrograph of choke-bore porous chrome-plated cylinder barrel representative of barrel surfaces at the middle of ring travel on the major-thrust face. Condition before silver plating and before test 8. Estimated porosity, 40 percent. X108.

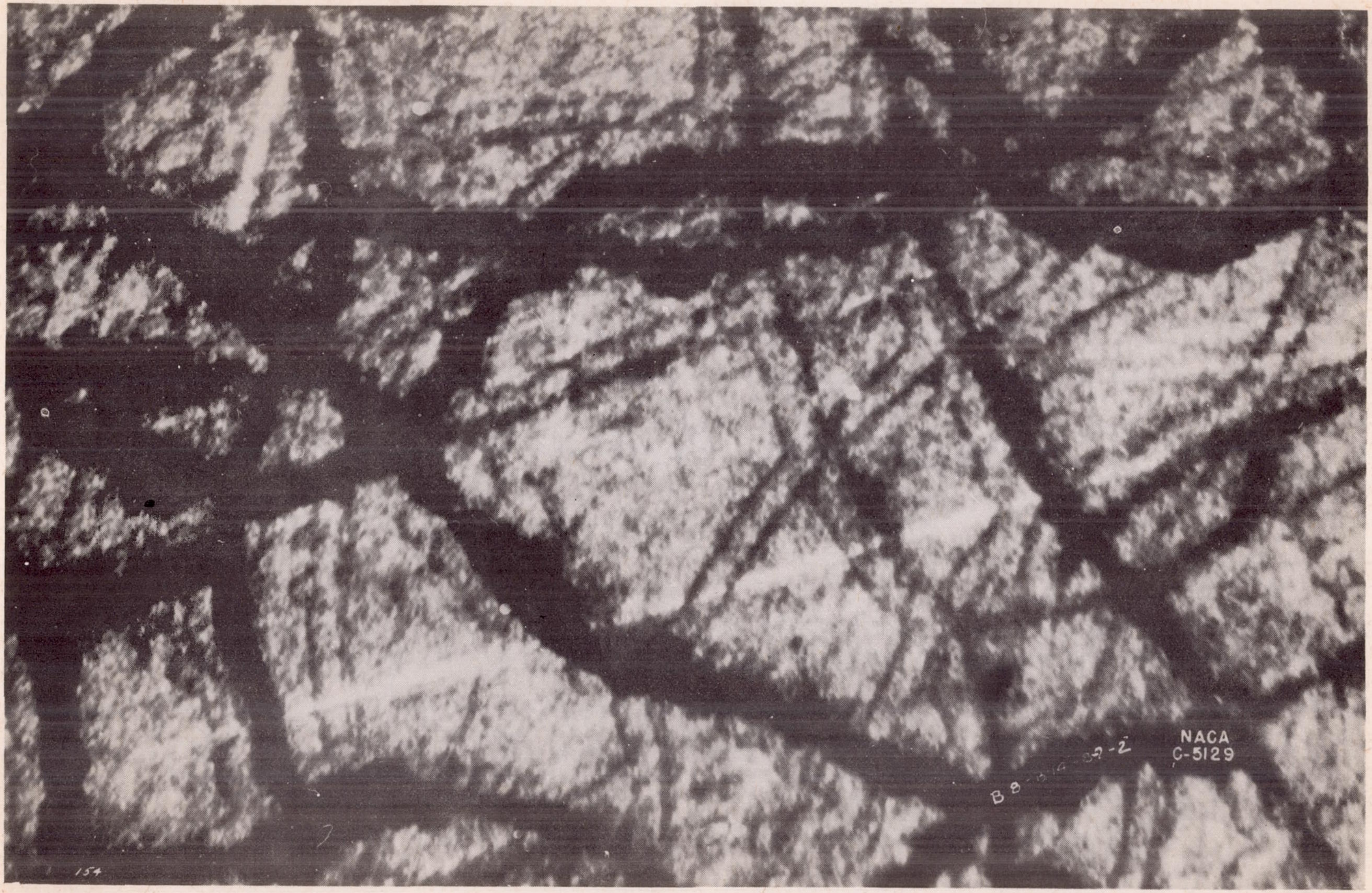

Figure 7. - Photomicrograph of same area as figure 6 after silver plating and before test 8. X108.

Figure 8. - Photomicrograph of same area as figures 6 and 7 after test 8. X108.

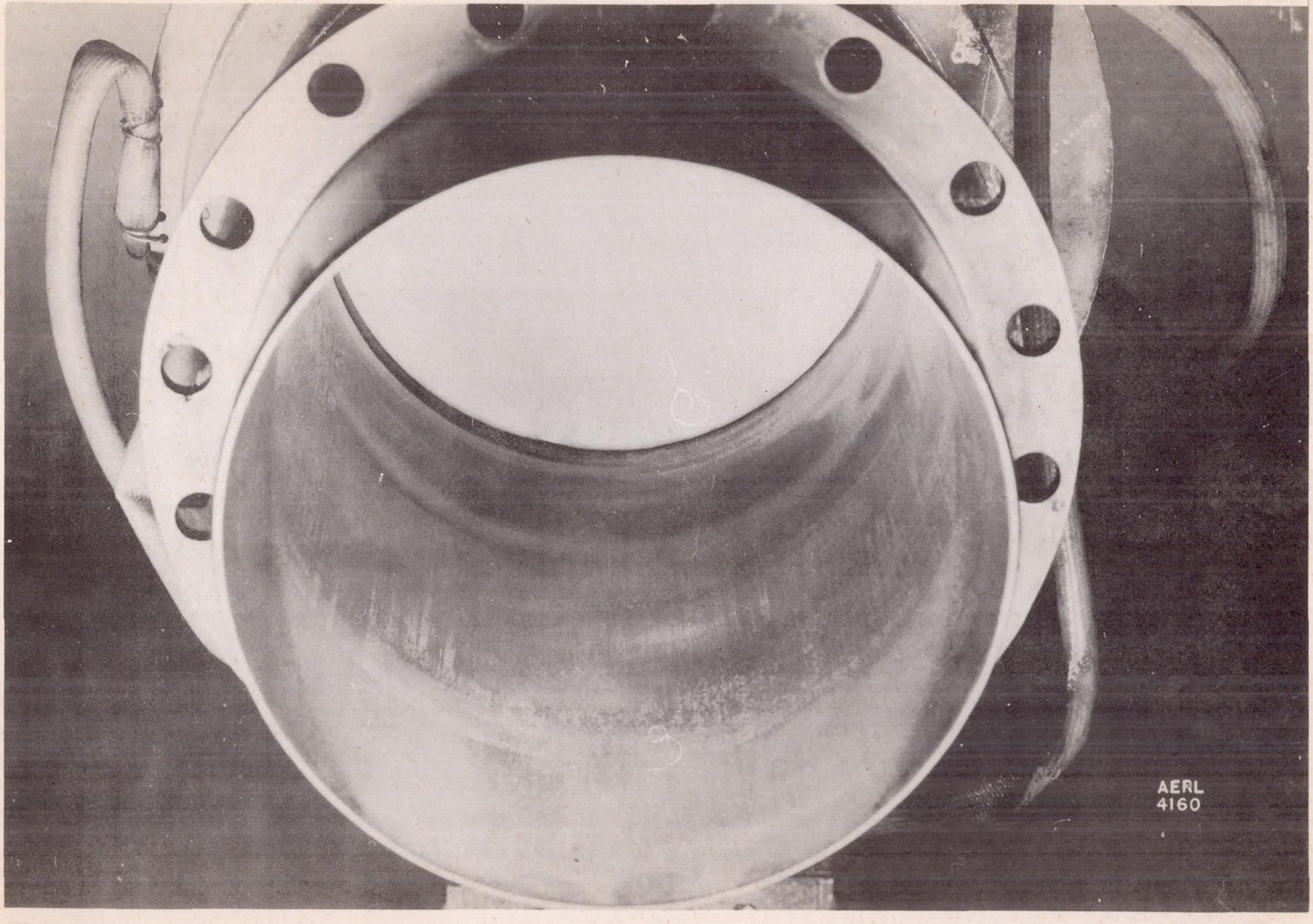

Figure 9. - Downstream face of choke-bore porous chrome-plated cylinder barrel with a silver overplate. Condition after test 8.

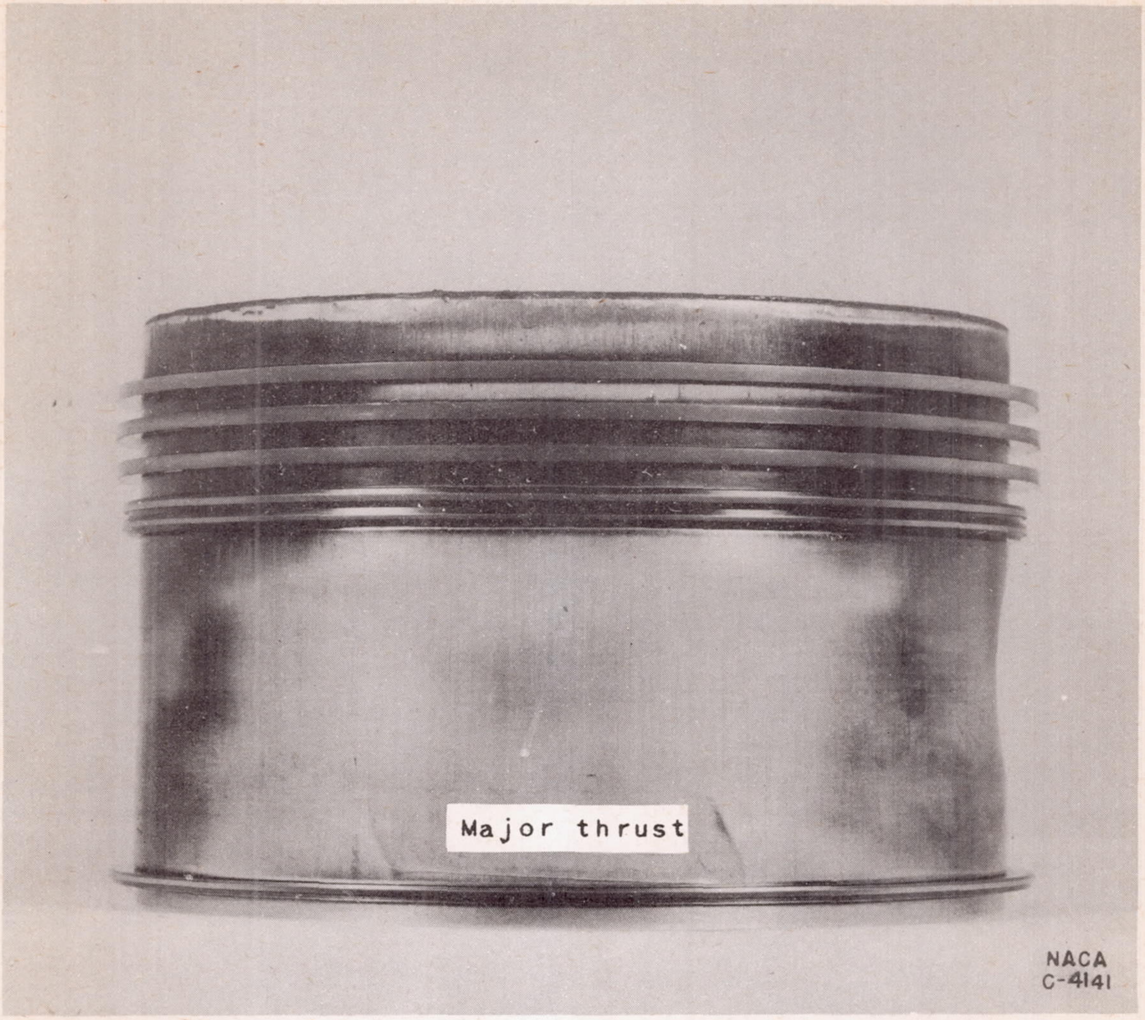

Figure 10. - Major-thrust face of piston run in a choke-bore porous chrome-plated cylinder barrel with a silver over-plate. Condition after test 8.

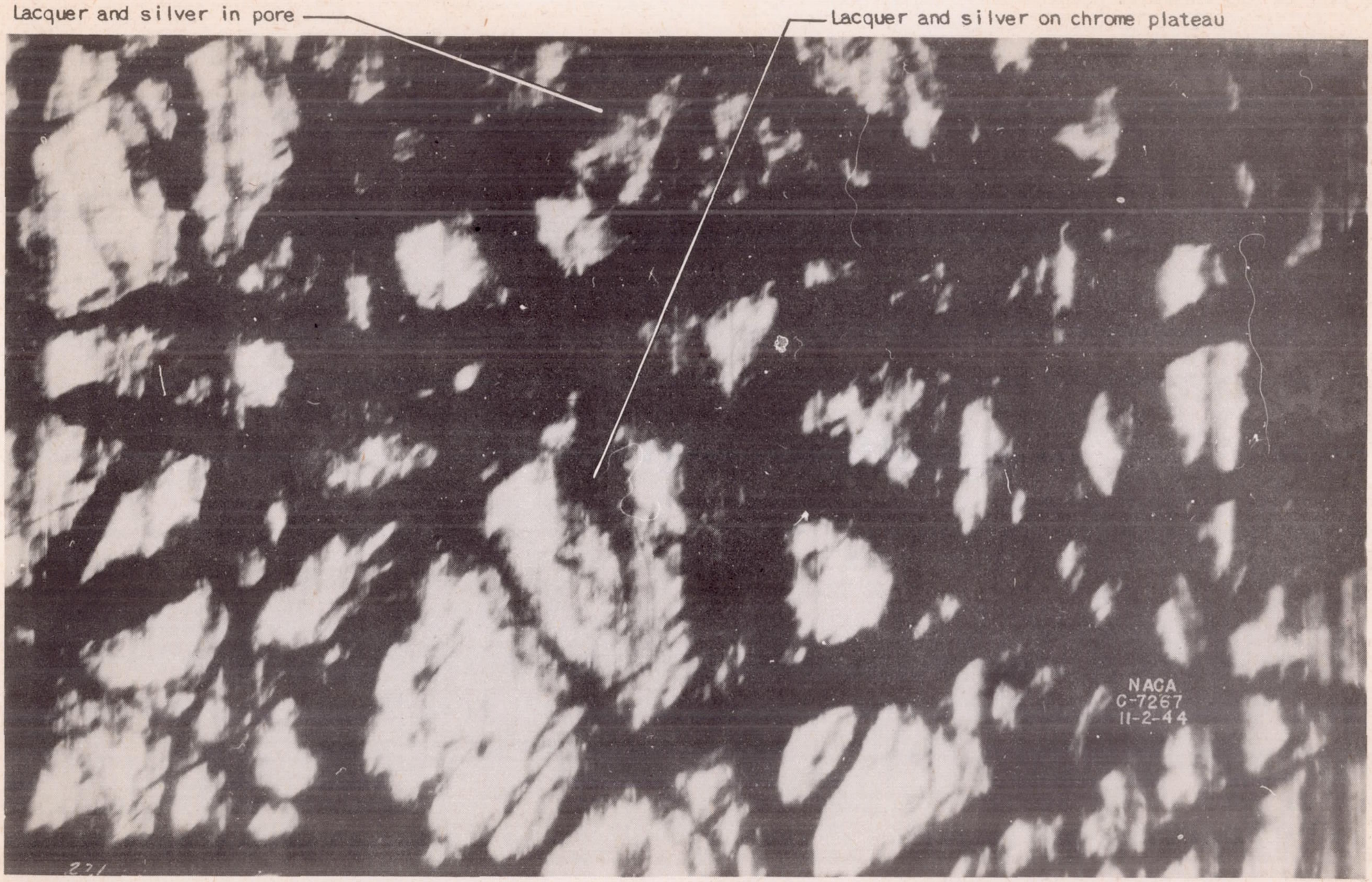

Figure 11. - Photomicrograph of choke-bore porous chrome-plated cylinder barrel representative of bore surface at top of ring travel on the upstream face. Condition after test 8. X108.