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PROGRESS REPORT ON ENGINE AIR CLEANING

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to
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NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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(Inspection of Two Helicopter Engines)

A 200 H.P. air cooled Franklin engine, Model 6-335-6, Serial #E 600422, with six opposed cylinders was shipped here from Fort Sill, Oklahoma. According to information, the engine had been exchanged after 281 hours of service because of high oil consumption.

The cylinders and pistons of the engine were disassembled and cleaned with varsol. No marks of extensive wear were noticed on any part and the extent of wear appeared similar on all cylinders and pistons. Figure 1 shows a photograph of two pistons with connecting rods. The right hand piston was only washed and appears as it was removed from the cylinder whereas on the left hand piston the rings were taken off and the walls scraped free of carbon so that the score marks above the first compression ring are clearly visible. These score marks indicate that dust particles of considerable size had reached the cylinders through the air induction system. The piston skirts appeared smooth and showed no score marks.

To determine the extent as well as the similarity of the wear five micrometer caliper measurements were made on each piston. The first three measurements were made at right angles to the piston pins:

a. Above the first ring,

b. Just below the oil ring and

c. At the bottom of the skirt.

The two other measurements were made in the axis of the pins:

d. Above the first ring and

e. Just below the oil ring.

The following table shows the results of these measurements:

TABLE I

	Piston #1	#2	#3	#4	#5	#6
a.	4.4715	4.4741	4.4730	4.4730	4.4710	4.4725
b.	4.4955	4.4950	4.4955	4.4962	4.4948	4.4961
c.	4.4971	4.4978	4.4980	4.4980	4.4975	4.4985
d.	4.4713	4.4732	4.4732	4.4732	4.4715	4.4730
e.	4.4825	4.4855	4.4841	4.4841	4.4835	4.4830

This table indicates that all pistons are worn off more at the top then on the lower end. The difference between the measurements at the top and across the skirt varies from 0.0237 inch on piston #2 to 0.0265 inch on piston #5, the average difference was 0.0253 inch in the plane vertical to the piston pins. The difference of measurements in the axis of the piston pins was much smaller, as was to be expected, since there was no tilting force in this plane. As the engine had been operating in a vertical position the piston pin covers were worn

smooth and shiny on the lower side and corroded with carbon on the upper side. However, no difference in the piston wear was noticed between these two sides. All upper compression rings had worn loose in the grooves, whereas the second rings had become stuck in the grooves with soot and had to be tapped to be removed.

Figure 2 shows a photograph of two pairs of valves, the left pair as it was removed from the cylinder and the right hand pair with the carbon brushed off. The valve lip of the cleaned exhaust valve was badly pitted but there was no wear noticeable on the valve stems.

All valve springs appeared to be in good condition.

The cylinder diameters were determined twice along a line drawn between the valves and twice at a right angle to that line. One pair of readings was taken near the top dead center of the piston travel and the other near the bottom of the cylinder. At TDC the maximum diameter measured was 4.5071 inch in cylinder #4 and the minimum was 4.5020 inch in cylinder #3, the average valve was 4.5041 inch. In all cases, the cylinders were smaller at the base, the diameters ranged from 4.5049 inch to 4.0503 inch, the average 4.5022 inch.

All cylinders appeared in a good condition as indicated in the photograph of cylinder #2 in figure 3. There were no around the skirt of the lower ring and deposited with carbon on the upper side. However, no difference in the piston wear was noticed between these two sets. All upper compression rings had been loose in the grooves, whereas the second rings had become stuck in the grooves with soot and had to be forced to be removed.

Figure 3 shows a photograph of two pairs of valves, the left pair as it was removed from the cylinder and the right hand pair with the carbon brushed off. The valve lip of the exhaust valve was badly burned and there was no other outstanding on the valve faces.

All valve seatings appeared to be in good condition.

The cylinder diameters were determined using dial gauge a dial gauge between the valves and again at a right angle to this axis. This pair of readings was taken near the top dead center of the piston travel and the other near the bottom of the cylinder. At TDC the maximum diameter measured was 4.5072 inch in cylinder #4 and the minimum was 4.5042 inch in cylinder #2, the average value was 4.5061 inch. In all cases, and cylinders were measured at the base, the diameters ranged from 4.5036 to 4.5060 inch, the average 4.5048 inch.

All cylinders appeared to be in good condition as indicated in the photograph of cylinder #4 in Figure 4. There were no visible score marks as on the pistons. The seats of the intake valves showed very little or no pitting at all, whereas all the exhaust valve seats were more or less pitted.

An oily film noticed in the intake manifold was washed out with gasoline to determine whether dust particles from the induction air could be found there. The gasoline was allowed to settle and a few drops were put on a microscopic slide which was then placed on the bottom of a beaker with clean gasoline to remove the green dye that was used to identify the gasoline and had deposited on the manifold walls. After drying, the slides were inspected on a micro-projector and dust particles up to 100 micron size were found. A high percentage of the larger particles could clearly be identified as sand.

Results of the Inspection of An 0-470 Engine

A 213 H.P. air cooled Continental engine with opposed cylinders, Model 0-470-11, Serial #T 100608, arrived at this Bureau from Fort Bragg, N. C., just after the inspection of the Franklin engine was completed. Information on a form DD 535 stated that this engine had operated 255-3/4 hours and had been exchanged because of low compression and excessive oil consumption (4 quarts per hour).

The inspection of this engine was made in the same manner as that of the Franklin engine, and the general condition was

found to be about the same. Figure 4 shows the second piston with connecting rod, wrist pin and the first compression ring. This ring was found broken in the middle when the piston was removed from the cylinder. The outside of this ring was shiny and smooth only about 1/2 inch from either of the four ends, whereas the rest of the outside was black and covered with carbon. This showed that only the ends had been bearing against the cylinder walls and the break of the ring must have occurred while the engine was still in operation. There are score marks on the lower part of the piston but these are much finer than those on the upper part.

Figure 5 shows the first compression ring of cylinder #3 inserted in the lower part of that cylinder, leaving a gap of 0.31 inch. This gap indicates an outside wear of that ring of nearly 0.05 inch.

The following table shows the piston measurements taken from this engine in the same order as indicated in Table I.

TABLE II

	Piston #1	#2	#3	#4	#5	#6
a.	4.9652	4.9630	4.9650	4.9650	4.9650	4.9645
b.	4.9856	4.9844	4.9843	4.9848	4.9840	4.9848
c.	4.9910	4.9910	4.9920	4.9923	4.9920	4.9919
d.	4.9673	4.9675	4.9670	4.9675	4.9672	4.9671
e.	4.9861	4.9875	4.9854	4.9870	4.9860	4.9868

Measurements of the various inside diameters of the cylinders were made in the same manner as in the O-335. At top dead center, the maximum diameter was 5.0035" in cylinder #2, the minimum measured was 5.0000" in cylinders #5 and #6, and the average was 5.0015". At the bottom of the piston travel the maximum diameter was 5.0050" in cylinder #2, the minimum 5.0005" in cylinder #5, the average was 5.0029".

A microscopic examination of the deposits from the intake manifold, conducted in the same manner as previously described, revealed the presence of dust particles of up to approximately 250-micron size, also some fibrous particles were noticed.

Examination of The Crankcase Oil

Approximately two gallons of used engine oil were received with each of the two engines and it was assumed that this oil had been drained before packing the engines. Cans A and B were packed with the Franklin engine and can C was packed with the Continental engine.

To obtain information as to the content of foreign matter all three cans were turned over to the Pure Substances Section of this Bureau for a spectographic examination. A copy of this report is attached and shows that metallic impurities and silicon were found present only as minor constituents of between 0.01 to 0.10% by weight.

It was considered possible that due to the long standing of the cans the heavy metallic and silicon particles had settled out and adhered to the bottom in such a manner that they could not be removed by suction as had been the spectroscopically examined samples. A special spoon was made and sludge scraped off the bottom of each can. These samples were microscopically examined in a way similar to that found in the intake manifolds. The solid particles observed were below 20 micron size and small in number. This leads to the conclusion that either no appreciable amount of dust penetrated into the crankcase breather system or the sample oil was drawn off the top of the oil sump and the heavy material left there and wiped before the engines were packed. The oil sumps of both engines did not contain noticeable traces of sludge.

Test Results On A Rotating Filter

A series of 64 tests was conducted with a regular 7-1/2 inch squirrel cage blower running in reverse. The only modification made on this blower consisted in a 1/2 in. wide slot cut into the scroll close to a point where it is nearest to the blower wheel. This point where the concentration of the dust was high was selected for the blow-down. Figure 6 shows the arrangement made. Air is drawn through the rotating filter by a blower, not shown on this photograph. A

3 inch duct visible in the upper center has an orifice flow meter installed and draws the air from the inside of the squirrel cage. The blow-down is flown through a rubber hose into a rectangular canister underneath the filter. This canister contains a flannel bag which retained most of the dust rejected by the rotating filter. The air flow rate through this bag was also measured with an orifice flow meter and was adjusted to maintain the desired ratio between total air flown through the filter and the blow-down air. A variable speed motor permitted adjustment of the filter speed in a wide range.

The dust is introduced into a square duct attached to the blower by means of an aspirator operated with compressed air. The aspirator picks up the dust out of either of two concentric grooves on a turntable attached to a Graham variable speed transmission drive. A hopper feeds the dust into the grooves of the turntable to an adjustable height so that the feed rate is constant to a very close degree. The hopper has a vibrator attached to avoid clogging of the feeder tube.

Four feet from the filter the air sampling device is installed as shown in Figure 7. Exchangeable nozzles from 1/4 inch to 13/32 inch diameter permit the drawing of sampling air isokinetically over a wide range of air velocities in the duct at a flow rate of between 1 cfm and 2 cfm. The maximum

I [illegible] were visible in the upper [illegible] and [illegible] from [illegible] and drawn [illegible] the [illegible] to the [illegible]. The [illegible] is drawn through a [illegible] into a [illegible] filter. [illegible] a flannel bag which [illegible] most of the dust [illegible] by the [illegible] filters. The air flow rate through this bag was also measured [illegible] and was adjusted to maintain the [illegible] between [illegible] air flows through the filter and the flow-meter [illegible]. A [illegible] of the filter would be a wire screen.

The dust is introduced from a [illegible] to the filter by means of [illegible] with [illegible] air. The [illegible] of the [illegible] speed [illegible] of the [illegible] a [illegible] of the [illegible].

From there, from the filter the air sampling [illegible] is shown in Figure 7. [illegible] from 1/8 inch to 1/16 inch diameter permit the [illegible] of sampling [illegible] over a wide range of air velocities in the [illegible] at a flow rate of between 1 cfm and 4 cfm. The [illegible] flow rate of the sampling air is determined by the limited tensile strength of the absolute filter a 0.3 micron glass fibre paper which is clamped in a 3 inch holder and will retain 100% of all dust particles above 0.3 micron size. The sampling paper holder is clamped between two pipe bell caps and air is drawn through it by special vacuum pumps. The samplers are weighted before and after each test to the nearest 0.1 milligram.

Figure 8 is a photograph of the test panel showing in the center a manifold which permits the calibrated gas meter to be put in series with either of the two constant velocity flow meters and to control the air flow rate through the sampler or cascade impacter, as is desired. The flow meters are used to adjust to a certain flow rate and to maintain it constant during the test period whereas the gas meter is used to determine the actual airflow volume. This volume divided by the test duration, determined with a stop watch, was found to furnish a more precise value for the sampler airflow rate than could be obtained with the flow meters. The inclined gage at the top of the board is parallel-connected with the first U-tube manometer to show the pressure drop across the orifice in the 3 inch duct. The orifice flow meter was designed and the flow rates calculated in accordance with the A.S.M.E. handbook "Fluid Meters, Their Theory and Application".

The other three manometers show the pressure at the orifice plate, the pressure drop across the sampler, and the vacuum at the sampler flow meter.

The filtering efficiency of the rotating filter was determined in two independent ways: (1) by using the dust collected from the blow down in the flannel bag

$$E_B = \frac{D - d_B}{D} \times 100\%$$

where E_B = efficiency determined from the blow-down, %

D = total dust introduced into the filter, g

d_B = weight increase of the flannel bag, g

(2) by using the glass fibre sampler

$$E = \frac{D - d_s \times R}{D} \times 100\%$$

where E_s = efficiency determined from the sampler method, %

d_s = weight increase of the sampler, g

R = ratio of total airflow rate to airflow rate through the sampler.

A series of preliminary tests was conducted during which the dust was introduced into the duct directly and the efficiency determined at isokinetic flow at various flow rates was zero within a satisfactory margin. In subsequent tests the E_s values

were always higher than the E_B values and the conclusion was drawn that the flannel bag pass d a certain amount of dust. All tests were made with A. C. Spark Plug dust coarse.

The airflow rate through the filter was tested between 50 cfm and 250 cfm at speeds ranging from 300 RPM to 1940 RPM. The percentage of blow-down air was changed between 4.1% to 24% whereas the dust concentration was maintained at close to 35 milligrams per cubic foot, the minimum concentration u ed was 24.0 mg/cu. ft. and the maximum was 40.9 mg/cu.ft.

The efficiencies observed with the sampler method averaged ?7.2 and those observed with the blow-down bag averaged 79.3%. No distinguished pattern as to a marked influence of any one of the variable indicated above and in the range tested could be established to a degree of certainty.

Test Of Air Maze Aircraft Filters

A group of seven Air Maze aircraft filters was furnished this laboratory for the purpose of determining their operational characteristics. These filters had an outside dimension of 7" x 6-1/2" x 1" and an effective filter area of 6-1/2" x 6", they had a flock cover screen type filter medium and according to an Air Maze catalogue had a design face velocity of 1050 ft/min corresponding to 305 cfm for this size filter.

There were two new filters and five used ones. Three of the used filters carried information of their time of service,

the other two did not have any identification. The two new filters appeared to have been oiled in the factory, most of the oil, however, seems to have disappeared in storage. The holding clips and gaskets were removed from the filters for the purpose of installation in the test apparatus. The following table summarizes the condition of the filters as received, their weights, stripped of gasket and holding clips and the pressure drop observed across the filters at 305 cfm airflow rate.

TABLE III

No.	Condition	Weight, g	Pressure Drop, in WG
1	used	234.9	1.38
2	used 987 hrs.	239.7	1.14
3	used 331 hrs.	248.4	1.12
4	used	222.9	0.75
5	used 1226 hrs.	237.6	0.83
6	new	218.4	1.97
7	new	220.6	1.93

A test apparatus similar to that described for the rotating filter was built. However, a dust sampler was also drawn upstream the filter for determining the dust content in the air stream at the same relative position as downstream. Besides two sampling stations were provided to investigate the practicability of applying the discoloration test method for

engine air cleaners; the discoloration method has been found the outstanding method for determining the operational efficiency for dust filters and has been well developed in this Bureau. The number of tests conducted at this time do not permit a decision on the merits of this method.

The efficiency of the filters was determined as

$$E = \frac{U - D}{U} \times 100$$

where E = effiency, %

U = dust collected on the upstream sampler, g

D = dust collected on the downstream sampler, g

The efficiency was also determined as the ratio of the actual weight increase of the test filter and the amount of dust introduced into the apparatus. The efficiency values obtained by the latter means agreed with those determined with weighing the sampler, but were always a little lower because of the unavoidable loss of some dust, when removing the test specimen from the apparatus.

Figure 9 shows a photograph of the entire test duct with the test panel in the background. The adapter for holding the filters is in the middle of the duct and below it on the floor is shown an inverted funnel used for oiling and draining four filters at one time. Figure 10 shows a close-up view of the test panel.

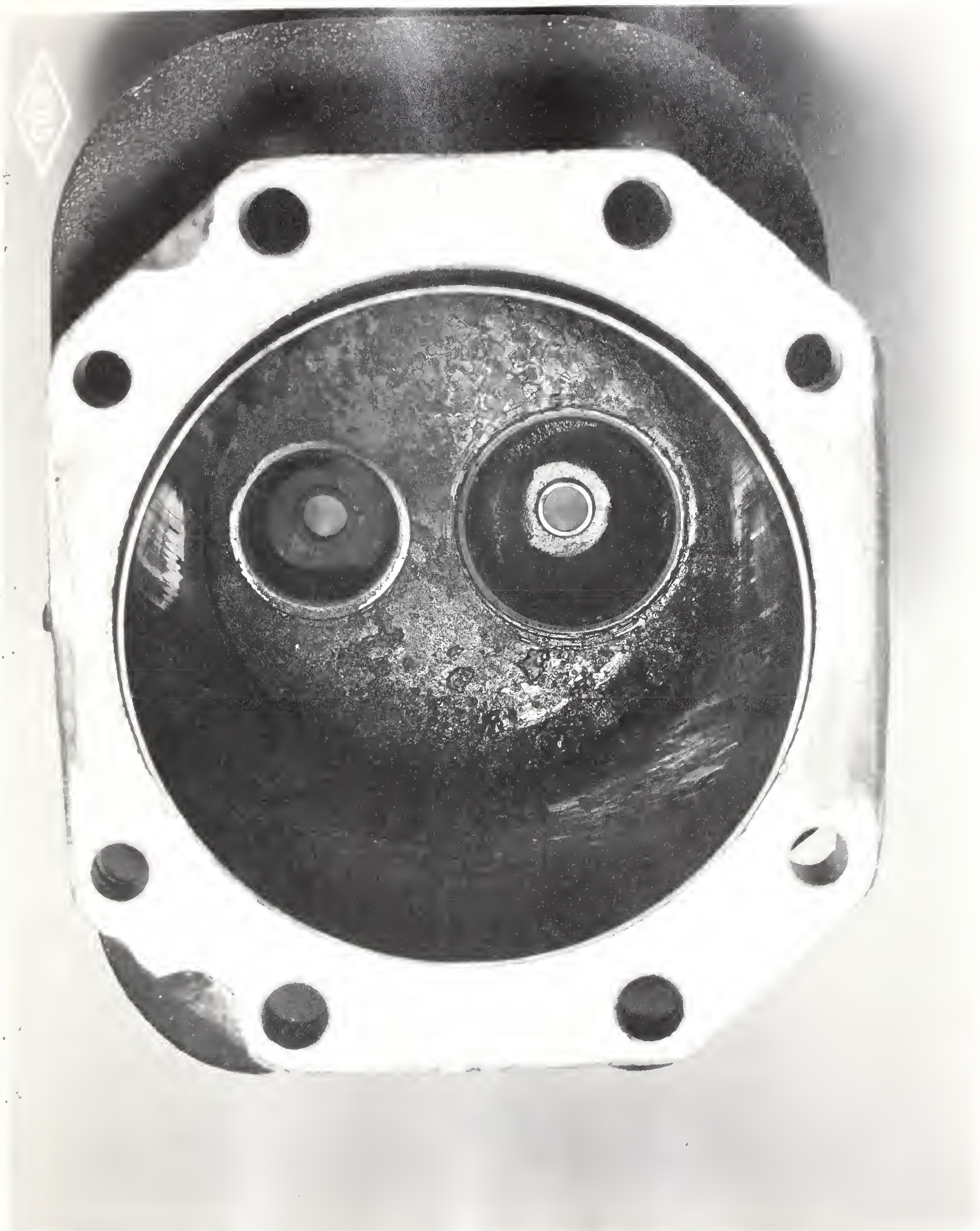
To determine the effect of oiling on these kinds of filters the two new filters were loaded up to capacity with A. C. Spark Plug dust fine and the efficiency determined by weighing the filter after 20g dust had been introduced into the air stream with a dust concentration of approximately 20 mg/cu.ft. The airflow rate was maintained at 305 cfm, except that at the end of the test with the oiled filter the pressure drop across the filter increased to such a value that the exhaust capacity was reduced to 150 cfm. The results of these tests are plotted in figure 11 which shows that the efficiency of the oiled filter remains well above 90% as the filter clogged up for all practical purposes. The pressure drop across the filter measured as 23.2 in W.G. at 150 cfm would have been very much higher if the airflow rate of 305 cfm could have been maintained by the exhaust blower. The not oiled showed an efficiency of 84.7% at the beginning of the test which dropped down to 39.2% the pressure drop at that efficiency had increased to 20.8 in. W.G. and the test was broken off because the efficiency was below any useful value and also the limit of the blower capacity was reached.

In another test with a new oiled filter it was determined that the introduction of 40g of dust increased the pressure drop from 3.2 in. W.G. to 15.6 in. W.G. and the efficiency computed with the sampling method was 96.1%. It was noticed that the

specification MIL-F-7194 would require the pressure drop of this filter not to exceed 8 in. W.G. after introducing approximately 58g of dust into the air stream; the required filtering efficiency of 90%, however, is well exceeded.

FIG. 1

FIG. 2



IG. 3

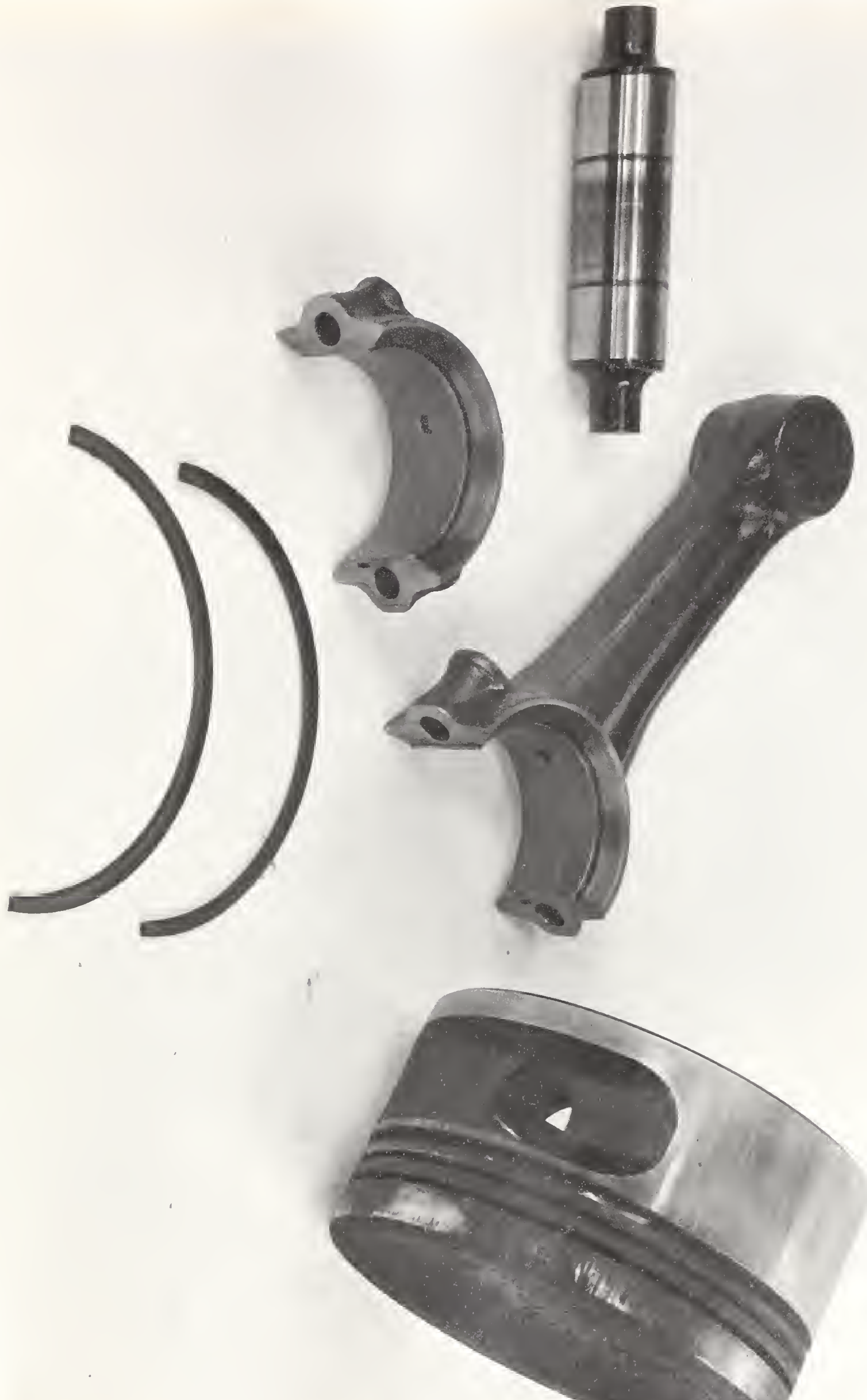


FIG. 4

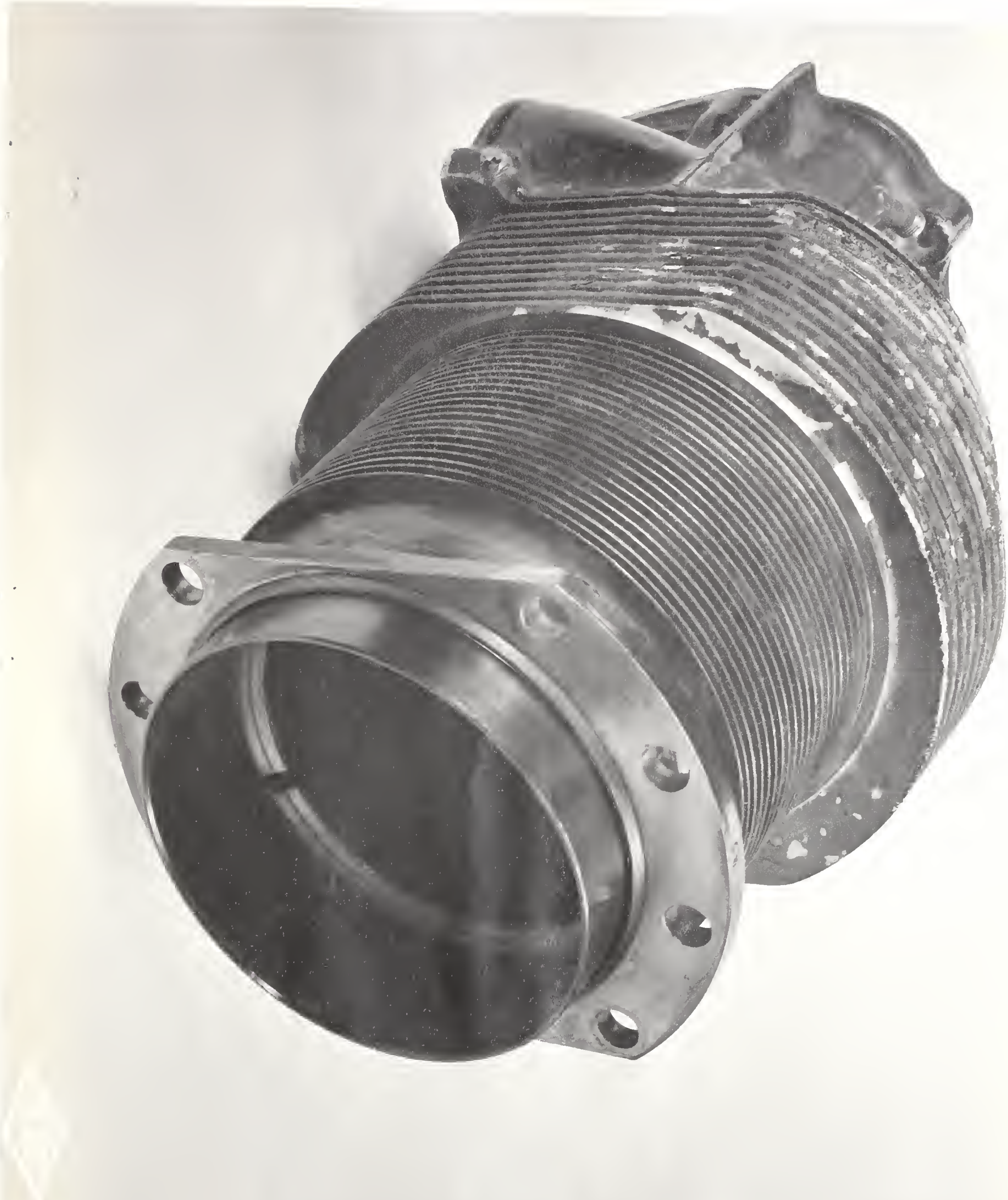


FIG. 5

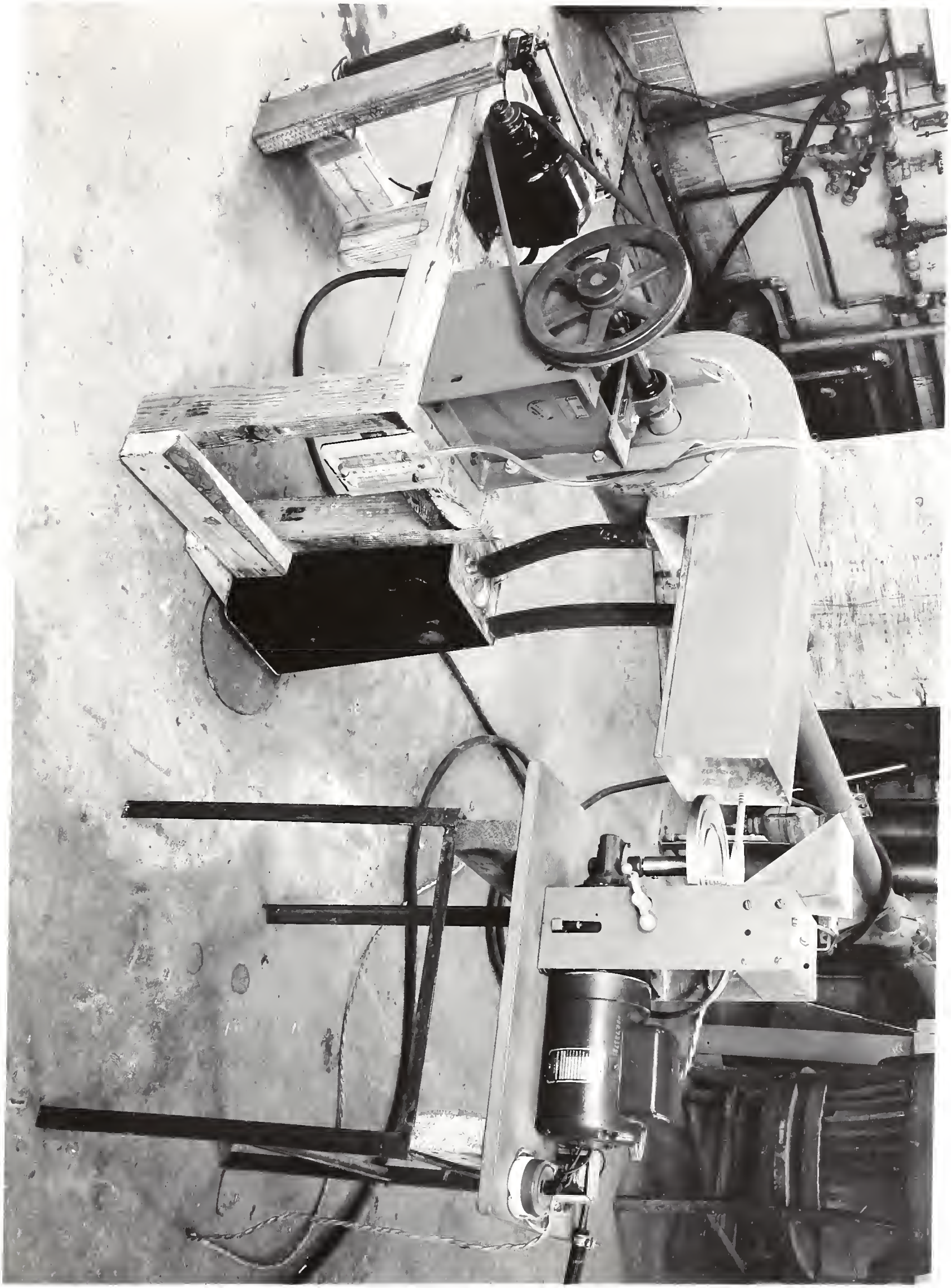


FIG. 6

FIG. 7

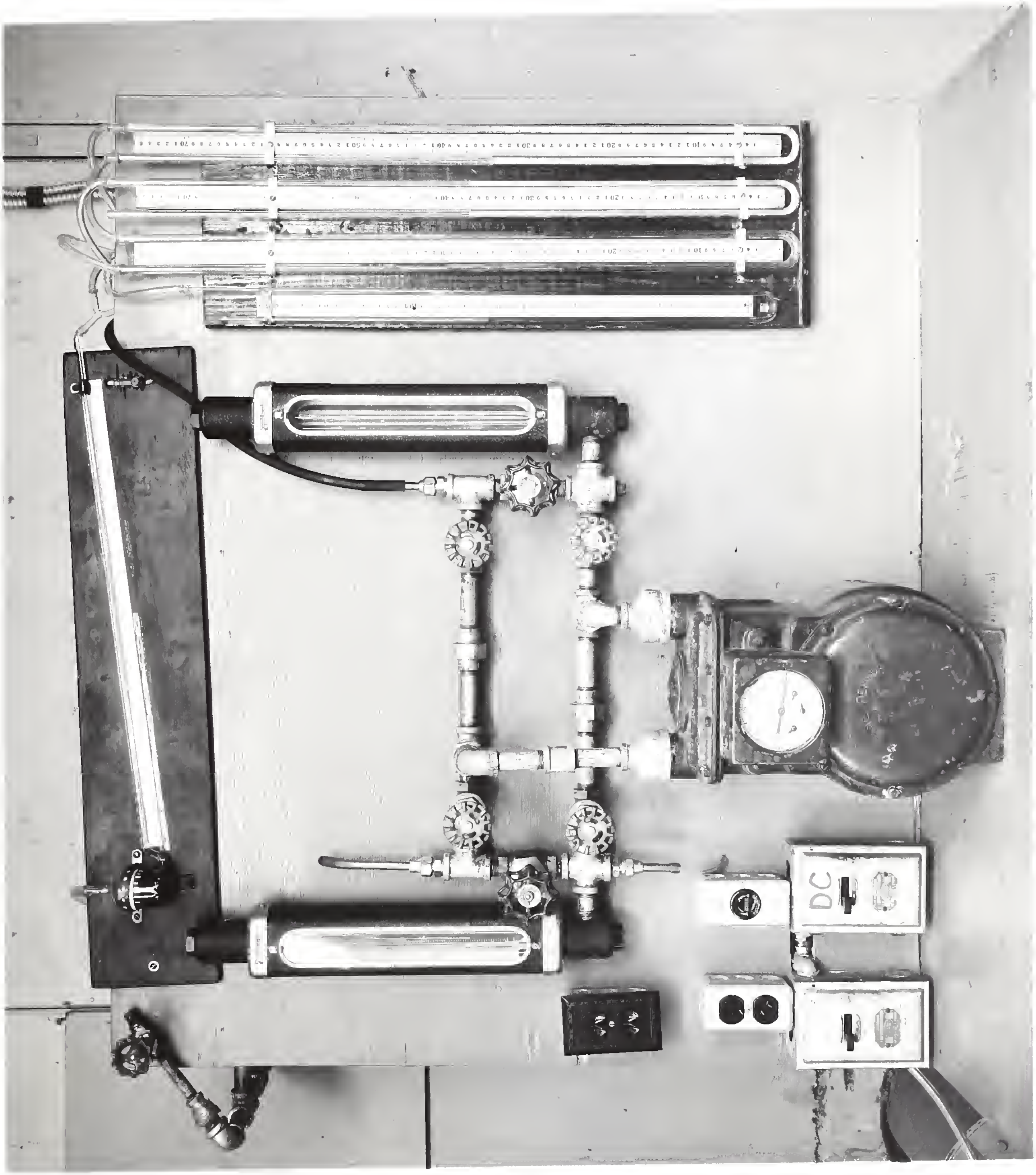


FIG. 8

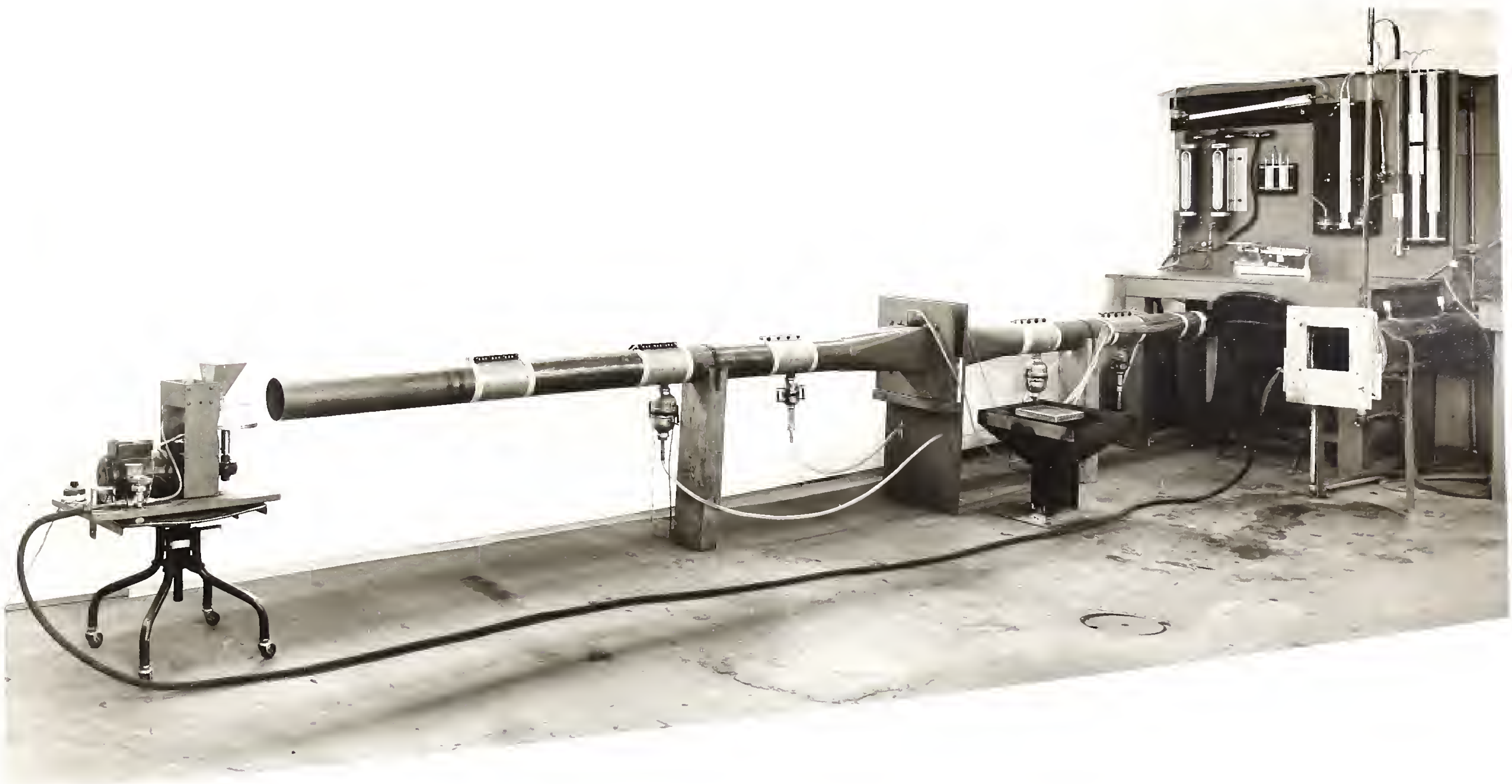


FIG. 9

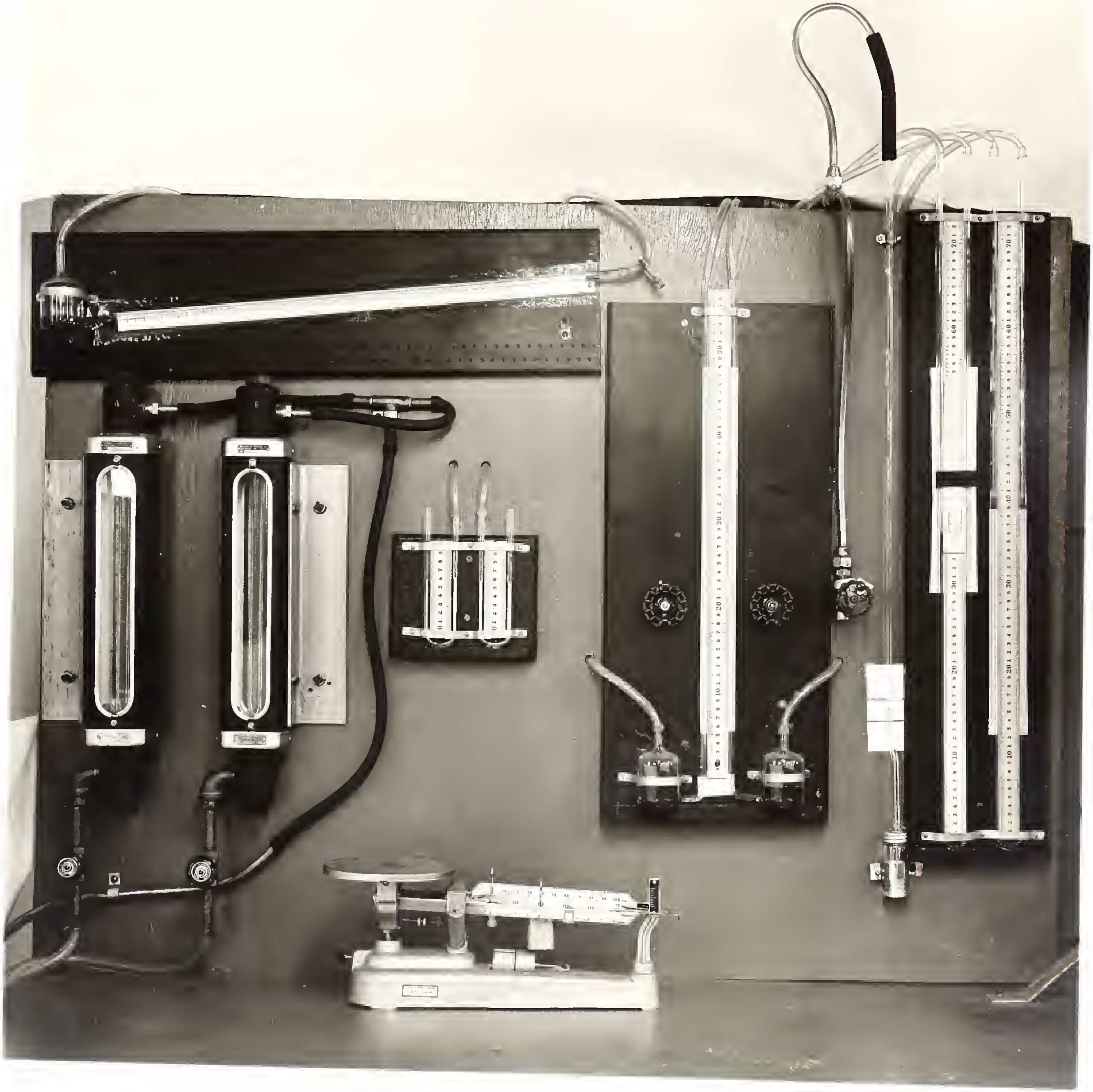


FIG. 10

EFFECT of OILING of AIRMAZE AIRCRAFT FILTERS at 1050 Ft/Min F. V.

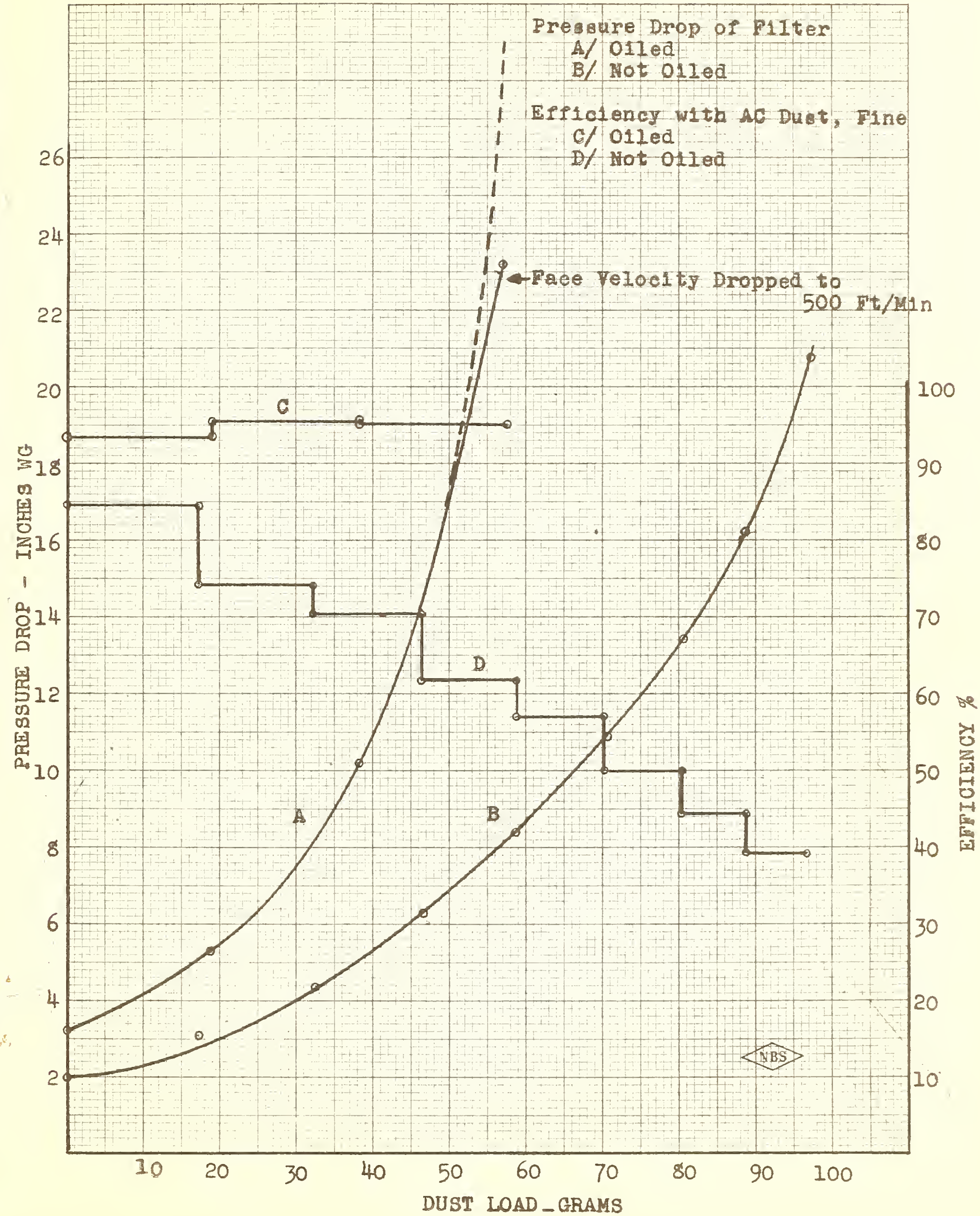


FIG. 11