NATIONAL BUREAU OF STANDARDS REPORT

4022

PERFORMANCE OF FRAM PAPER FILTERS, MODEL CA-100PL

by

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U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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NATIONAL BUREAU OF STANDARDS REPORT

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Heating and Air Conditioning Section
Building Technology Division

To

Engineering and Development Branch
Office of the Chief of Transportation
Department of the Army
Washington, D. C.

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

Performance of Fram Paper Filters, Model CA-100PL

Abstract

Several specimens of the Fram filter, Model CA-100PL were tested to determine the efficiency and pressure drop characteristics for a range of air flow rates from 40 to 150 cfm using coarse and fine test dust prepared by the AC Spark Plug Division. The dust filtering efficiency was found to be on the order of 98 to 99 percent for most test conditions by the gravimetric test method. Efficiencies obtained by weighing the filter element were about 2 1/2% lower on the average than those obtained by the gravimetric sampling method. Efficiencies obtained by the dust-spot method corroborated those obtained by weighing the filter element on one specimen. The small size and especially the light weight of this filter would make it practical for aircraft. However, the dust-holding capacity was found to be low, so that application of this type of filter appears to be restricted to an after-filter when the bulk of the dust has been removed by an effective pre-filter. The pressure drop across the filter at design air flow rate of 120 cfm and a suggested maximum dust load of 16 grams was about 2 3/4 inch W.G.

I INTRODUCTION

As part of the project "Air Filter Systems for Army Aircraft", the performance characteristics of a Fram CA-100PL paper filter were determined to establish the feasibility of using this type of air filter as an induction air cleaner for helicopter or other small aircraft engines.

II SPECIMEN AND TEST EQUIPMENT

The test specimens were manufactured by the Fram Corporation of Providence, Rhode Island, and furnished as representative of a series of induction air cleaners for mobile and stationary combustion engines. The test specimen consisted of a filter holder with several replacement filter cartridges. The cartridges, one of which is shown in Fig. 1, were cylindrical, made of a pleated paper ring, with woven wire screens on the inside and outside, and held rigid by two flat metal rings that covered the ends. The dusty air was to pass through the filter from the outside to the inside and the dust could collect on the surface or in the pores of the filter.

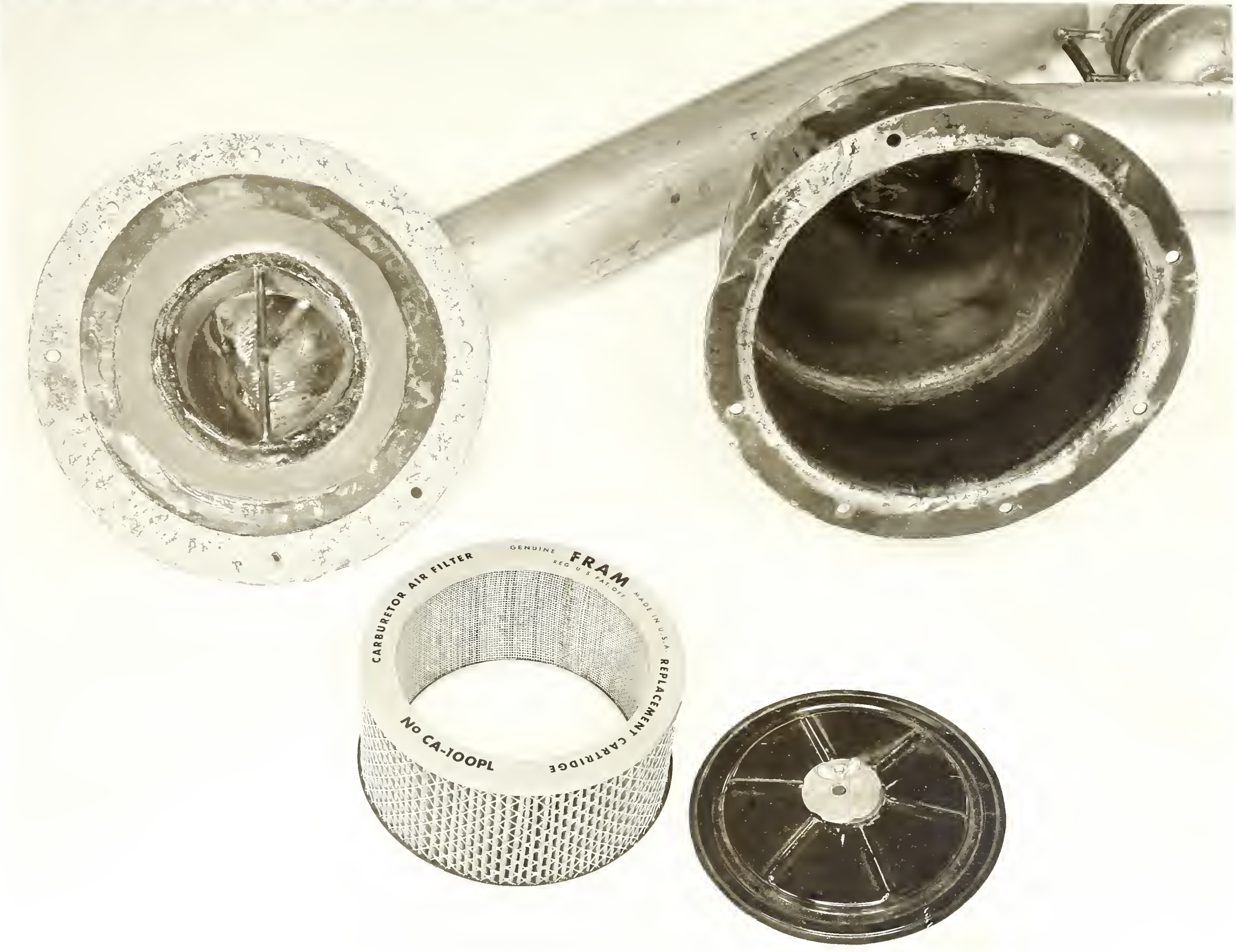
GENUINE FRAM
REG. U.S. PAT. OFF. MADE IN U.S.A. REPLACEMENT CARTRIDGE
CARBURETOR AIR FILTER
No CA-100PL

FIG.1

The manufacturer had furnished a holder for this filter suitable for attachment to the carburetor intake of an automobile and for operation as an intake air noise silencer. This adapter was not practical for installation in the test apparatus and a special adapter was designed for this purpose. It is shown assembled in Fig. 2 and disassembled in Fig. 1.

The dusty air entered at the bottom of the adapter through a 3 inch pipe. The filter was sealed against the upper half of the adapter around the rim of the filter and the dusty air was prevented from entering directly into the center of the filter by means of a cover plate at the bottom as shown in Fig. 1 This arrangement provided that all dust particles which fell off the filter were again picked up by the air stream. It was found that practically no dust accumulated underneath the filter or in the adapter during the various tests. The pressure drop across the filter was determined by taps installed in the filtered-air pipe near the upper adapter and in the lower adapter shell as shown in Fig. 2.

The air was drawn through the filter with an exhaust blower and the air flow rate was measured with an orifice flow meter designed in conformance with the A.S.M.E. Research Publication "Fluid Meters, Their Theory and Application". The test dusts used were AC Spark Plug Div. classified air cleaner test dusts "coarse" and "fine". The dust concentration was maintained at a desired value by feeding the dust from a hopper into the groove of a turntable mounted on a variable speed Graham transmission. A high pressure air aspirator picked up the dust from the turntable, breaking up most of the agglomeration, and supplied it to the inlet of the test duct.

The efficiency of the filter was determined by sampling the air upstream and downstream of the filter with identical sampling nozzles installed in the center of the duct through which air was drawn at the velocity prevailing in the duct. The dust was collected on glass fiber paper whose smallest fibers were about 0.3 micron in diameter. Tests of the air cleaning efficiency of similar papers by the Atomic Energy Commission indicate that this paper would retain more than 99.99% of all particles 0.3 micron and larger and could, therefore, be considered an absolute filter. The air flow rate through the upstream and downstream samplers was measured with two orifice flow meters that had been calibrated with a gas meter. Manometers connected to these flow meters were mounted on either side of a graduated rule to enable the operator to maintain equal flow through the samplers during each test. The filter efficiency was calculated from the formula

FIG.2

$$E_G = (1 - \frac{D}{U}) \times 100\%$$

where E_G = gravimetric efficiency, %

D = weight increase of downstream sampler,
U = weight increase of upstream sampler.

By weighing the filter cartridge before and after the tests another value for the filter efficiency was obtained as the ratio of the weight increase of the filter to the total amount of dust introduced. This value E_F was found to be consistently lower than E_G which was attributed to the unavoidable loss of some dust from the filter as it was taken out of the adapter.

III TEST PROCEDURE AND OBSERVATIONS

The filters were tested both with AC Spark Plug Division's classified air cleaner test dust "fine" and with a mixture of 50% each "fine" and "coarse" dust. The efficiency of the filter was determined at an air flow rate of 120 CFM and the pressure drop was observed at six different air flow rates ranging from 45 CFM to 150 CFM. For each test between 8 grams and 10 grams of dust were introduced into the duct system. It was found that this was the smallest amount that would produce an indicative weight increase of the downstream sampler. The weight increase of the samplers was determined with a laboratory balance to $\pm$ 0.1 milligram.

The dust concentration was determined as the ratio of the total dust introduced and the total volume of air circulated through the system during the test. The latter value was the product of the duration of the test and the air flow rate. As it was considered improbable that the concentration would have any appreciable effect on the efficiency of this type of filter no determination of the change of efficiency with varying concentrations was made. The average concentration used was about 20 mg/cu.ft.

Table 1 shows a summary of the results of 13 tests conducted to determine the efficiency of these filters. It will be noticed that part of the tests were conducted with AC Spark Plug Division dust fine and part with 50% each fine and coarse. Filter 1 was first loaded with fine dust, then rapped on the floor to remove as much as possible of the dust collected on the filter, and then loaded again with mixed dust. Whereas the average efficiency, E_G, of 98.4% of the first two tests on filter 1 with fine dust equaled that of the three tests with filter 3, the tests of this same filter after being cleaned using mixed dust

Filter

Test N

Type o

Weight
Durati
Dust C

Pressu
I
F

Weight
U
D

Effici
Weight
Filt
Effici

(a) A
(b) A

TABLE I

SUMMARY OF RESULTS

EFFICIENCY TESTS OF FRAM FILTER MODEL CA-100PL BY GRAVIMETRIC METHOD
(AIR FLOW RATE 120 CFM)

Filter No.		1				2			3			4		
Test No.		1	2	3	4	1	2	3	1	2	3	1	2	3
Type of Dust Used		fine (a)		half & half (b)		half & half (b)			fine(a)			half & half(b)		
Weight of Dust	g	10.112	10.109	10.120	10.132	10.144	8.070	8.147	8.669	8.658	8.675	8.010	8.022	8.024
Duration of Test	min	5'22	5'24	4'43	4'33	3'09	3'06	3'39	4'39	4'09	4'41	3'03	2'48	2'53
Dust Concentration	mg/ft^3	15.7	15.6	17.86	18.53	24.1	21.7	18.6	15.5	17.4	15.4	21.9	23.9	23.2
Pressure Drop across Filter														
Initial	in.WG	1.38	2.56	1.97	5.32	1.41	1.97	3.25	1.50	2.05	3.58	1.58	1.87	2.76
Final	in.WG	2.56	7.73	5.32	13.7	1.97	3.25	6.98	2.05	3.58	6.86	1.87	2.76	7.01
Weight Increase of Sampler														
Upstream	mg	181.6	183.4	135.2	132.0	145.8	128.4	121.0	168.4	195.0	169.2	165.3	197.8	171.2
Downstream	mg	4.4	1.6	3.3	2.6	5.0	2.2	2.6	4.0	1.6	1.4	2.9	0.6	0.5
Efficiency, E_G	%	97.6	99.1	97.6	98.0	96.6	98.3	97.9	96.7	99.2	99.2	98.2	99.6	99.6
Weight Increase of Filter	g	19.5		19.4			25.3			24.5			23.3	
Efficiency, E_F	%	96.5		95.8			95.8			94.1			96.9	

(a) AC Spark Plug Division classified test dust "fine"
(b) A mixture of 50% fine and 50% coarse AC Spark Plug Division classified test dust.

showed an average efficiency E_G of only 97.8% as compared to 99.1% average efficiency of filter 4 (a new filter) when operated under the same conditions. This comparison seemed to indicate that filter 1 must have been somehow damaged by the rapping process used for cleaning. The effect of structural damage likewise was apparent in filter 2, the average efficiency, E_G, of which was only 97.9% compared with 99.1% of filter 4 under equal conditions. It was noticed after the test that there was a small dent in one of the rims of filter 2 which apparently caused a leak of dust between the rim and the corrugated filter element.

The average efficiencies, E_F, obtained from the weight increase of the filters are about 2 1/2% below the efficiencies, E_G. The efficiencies determined from the filter weights are considered to corroborate approximately the results observed by the gravimetric method.

The efficiency of a fifth filter was determined using the NBS "Dust-Spot Method" as described in the paper "A Test Method for Air Filters" by R. S. Dill (ASHVE Transactions, Vol 44, p 379, 1938). In this method equal air samples upstream and downstream of the test filter are passed through known areas of Whatman No. 41 filter paper. The areas of the filter papers upstream and downstream are selected to obtain approximately equal change in light transmission through the filter paper spots.

The filter specimen used for this test had been loaded with dust and cleaned prior to the test. Its weight at the start of the test was about 7.6 grams higher than its weight new indicating that some dust remained on the filter element after cleaning.

The results of the dust spot test are shown in Table 2. Table 2 shows an increase in efficiency from 96.5% at a load of 6 grams to 98.1% at a load of 14 grams corresponding to an increase in pressure drop from an initial value of 2.17 in.W.G. to a final value of 11.77 in.W.G. at the end of the test. The efficiency, E_F, determined from the increase in weight of the filter was 98.8% for this test.

TABLE 2

SUMMARY OF RESULTS

EFFICIENCY TESTS OF FRAM FILTER, MODEL CA-100PL
BY THE DUST SPOT METHOD
AIRFLOW RATE 120 CFM

Dust Load Grams	Pressure Drop in W. G.	Aerosol	Dust Concentration Grams/1000 cu.ft.	Efficiency E_D %
0	2.17		-	-
6.1	3.04	A.C. Fine	7.2	96.5
9.2	4.69	"	7.7	97.5
14.3	11.77	"	8.3	98.1

E_F (from change in filter weight) = 98.8%

The relation of the pressure drop to the accumulated filter loads and the air flow rate was determined by measuring the pressure drops across filter 4 at different air flow rates before each test and after it was loaded to capacity. Table 3 shows the values observed and Fig.3 shows these values plotted on semi-log paper. This family of four curves shows that the rate of increase of pressure drop with increased air flow rate was greater at higher dust loads than for the clean filter or at lower accumulated loads.

TABLE 3

PRESSURE DROP vs AIR FLOW RATE (OBSERVED VALUES)
FRAM PAPER FILTER, MODEL CA-100PL

Air Flow Rate CFM	Pressure Drop Across Filter, in. W.G. — Load on Filter Element, grams: none	7.7	15.5	23.3
45	0.35	-	-	2.05
70	0.59	0.83	1.13	3.46
80	0.79	-	-	4.13
90	0.95	-	-	4.76
120	1.58	1.87	2.71	7.01
150	2.32	2.72	3.43	8.94

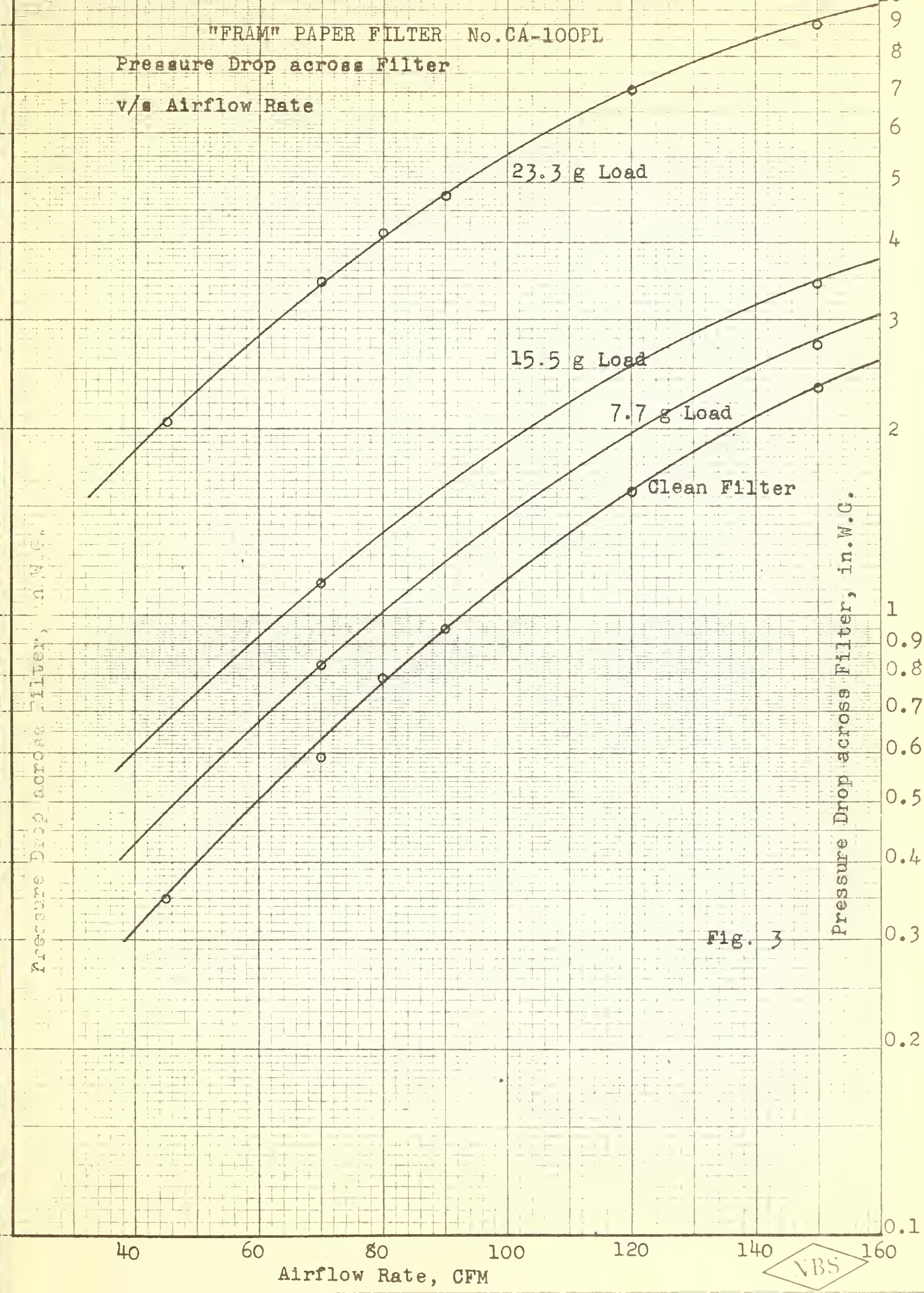
"FRAM" PAPER FILTER No.CA-100PL
Pressure Drop across Filter
v/s Airflow Rate
23.3 g Load
15.5 g Load
7.7 g Load
Clean Filter
Fig. 3
Pressure Drop across Filter, in.W.G.
Airflow Rate, CFM
40
60
80
100
120
140
160
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
2
3
4
5
6
7
8
9

Table 4 shows the values of the pressure drop at the observed filter loads and at selected air flow rates determined from graph Fig. 3. By plotting this table in Fig. 4 a family of five curves is obtained for each of five air flow rates between 40 and 160 CFM. This family of curves shows that the pressure drop increased almost linearly up to about 16 grams filter load for all air flow rates.

TABLE 4

FILTER LOAD vs PRESSURES DROP OF FRAM FILTER MODEL CA-100PL
(VALUES DETERMINED FROM FIG.3,
BASED ON OBSERVED VALUES TABLE 3)

Load Grams	Pressure Drop Across Filter, in W.G. Air Flow Rate, CFM				
	40	70	100	130	160
0	0.31	0.63	1.15	1.80	2.60
7.7	0.43	0.83	1.45	2.25	3.1
15.5	0.60	1.13	1.90	2.85	3.8
23.3	1.85	3.46	5.5	7.8	9.8

At dust loads in excess of 16 grams all curves bend to the right which indicates that the increase of the pressure drop, then, is no longer directly proportional to the dust load. The sharp change of curvature in the pressure drop curves in Fig. 4 at a load of about 16 grams suggests that the filter should be considered to be loaded to capacity when it has accumulated about 16 grams of dust.

The pressure drop across the fifth specimen, tested by the dust spot method, appeared to begin to increase more rapidly at a total load of about 8 grams of dust. However, when the disparity between the initial weight of this filter at the start of the test and its weight new is taken into consideration, its pressure drop characteristic is similar to that of the fourth specimen plotted in Fig.4.

The true pressure drop across the filter element may be slightly less than the measured values because of the difference in velocity head of the air at the two points of measurement. This error is probably less than 0.25 in W.G.

"FRAM" PAPER FILTER No. CA-100PL

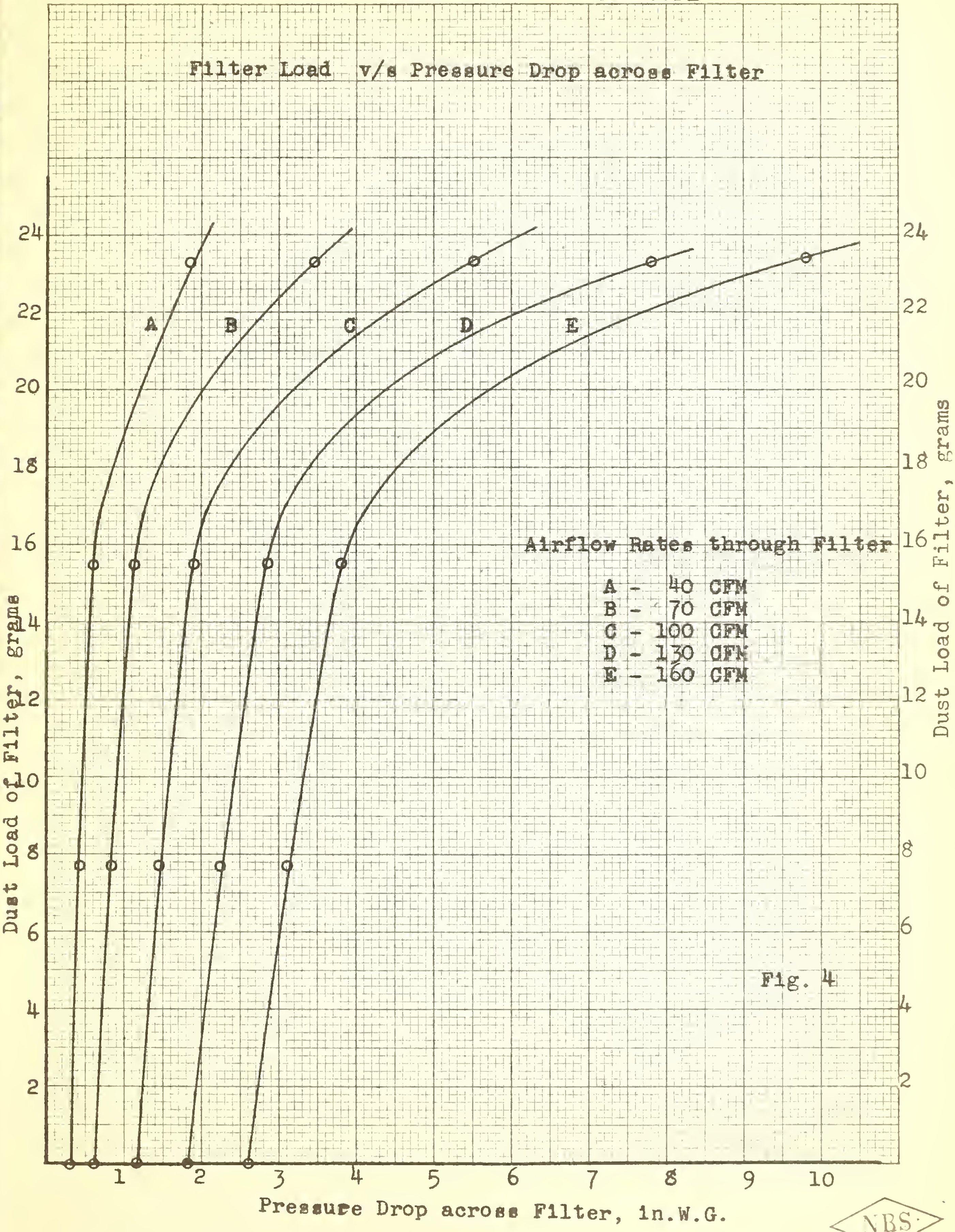

Fig. 4

IV DISCUSSION AND CONCLUSIONS

The efficiency of this type filter, tested under simulated operating conditions, was found to be 98.4% when using AC Spark Plug Division's classified air cleaner test dust "fine" and 99.1% with a mixture of 50% "fine" and 50% "coarse" dust. This filtering efficiency is believed to be a satisfactory protection against engine wear due to dust in the induction air of aircraft engines under any conditions. The pressure drop across the filter was moderate if the dust load did not exceed about 16 grams.

The filter cannot be readily cleaned, by rapping the filter on a solid surface as recommended by the manufacturer. This cleaning method damaged the filter frame in some instances which resulted in a loss of efficiency during subsequent operation. The dust holding capacity was rather low. At a design air flow rate of 120 CFM this filter would be filled to capacity in less than 7 minutes in a dust concentration of 20 mg/cu.ft. which can occur on dusty air fields.

This type of filter may have application, however, as an after-filter provided the bulk of the dust has been removed by an effective pre-filter and a further removal of dust is desired for ultimate extension of the life of the engine.

NBS