NASA-CR-159183

NASA Contractor Report 159183

THE TRANSFER OF CARBON FIBERS THROUGH A COMMERCIAL AIRCRAFT WATER SEPARATOR AND AIR CLEANER

Jerome A. Meyers

THE BIONETICS CORPORATION
Hampton, Virginia 23666

NASA Contract NAS1-15238
November 1979

NASA
National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23665

TABLE OF CONTENTS

N80-14359 #

LIST OF FIGURES

1.0 INTRODUCTION

This investigation was done under the NASA Graphite Fiber Risk Analysis Program. It is a part of the study being performed for commercial aircraft and is meant to augment data on the vulnerability of aircraft avionics and on estimates of the proportion of carbon fibers outside a closed aircraft that are transmitted to the electronics with the air conditioning system operating (i.e., the transfer function).

The specific objective of the testing was to determine the fraction of carbon fibers passing through a Water Separator and an Air Cleaner. Most commercial aircraft have water separators. Some do not have air cleaners, while one has a centrifugal air cleaner.

Use of corporate products or names of manufacturers in this report does not constitute official endorsement of such product or manufacturer, either expressed or implied by the National Aeronautics and Space Administration.

2.0 DESCRIPTION OF THE WATER SEPARATOR AND AIR CLEANER

2.1 The Water Separator

The test item was a Water Separator for a medium sized commercial aircraft. As air is cooled in the air conditioning system moisture begins to condense. The condensate is finely atomized and will follow the airstream unless it is removed. The water separator is used to collect and remove this moisture before the air enters the distribution system. See Figure 1 and 2.

The separator has an inlet shell with a bypass valve in front and a cone shaped metal support which supports a polyester coalescor bag. The outlet shell assembly has a baffle, a collection chamber and an overboard water drain.

The conical bag support fits inside the bag and has louvers shaped to impart a whirling motion to the air. As moist air passes through the bag, the bag is wetted and larger droplets of water are formed. The centrifugal force of the water keeps it close to the bag support as it passes downstream. A cylindrical baffle about the diameter of the outlet duct extends inside the downstream end of the water separator. To leave the separator the water and air must make a double reverse turn. The heavier water does not make the turn, stays in the collection chamber and gets vented overboard.[1]

The commercial jet aircraft being considered in the graphite fiber risk analysis study all use a water separator. Operation of the device is automatic and it sees maximum flow rates on hot days. When the ambient temperature is less than 5° C (40° F) there is little moisture in the air and cooling air does not pass through the device. The flow rate varies from zero to about 50 kilograms (110 pounds) of air per minute in medium aircraft to 68 kilograms (150) pounds) per minute in the large wide-bodies. Highest flows would occur above 27° C (80° F) at takeoff thrust. An estimated flow during ground operations on a standard day is approximately 27 kilograms (60 pounds) per minute.

2.2 The Air Cleaner

An air cleaner for a medium commercial aircraft was tested. It is used to purge the engine bleed air of impurities.

---

[1]Boeing Maintenance Manual/737 Aircraft. No. 21-51-0, pages 4, 5.

The air cleaner uses inertia to separate particulate matter from air. Air from the engine heat exchanger or precooler is ducted into the cleaner and is forced to abruptly change direction as it passes through louvers. The heavier particles continue downstream into a collector ring where they are purged and vented overboard. The clean air is ducted around the outside of the collector ring and into the pneumatic system of the aircraft.[2] Figure 3 shows a photograph of the air cleaner and Figure 4 is a sketch explaining its operation.

The air cleaner is provided to purge the engine bleed air of impurities whenever bleed air is used for air conditioning and the aircraft is on the ground or the flaps are extended. The air cleaner system is controlled automatically. It sees an air flow of about 27 kilograms/minute (60 pounds) on a 21° C (70° F) day. Flow may increase to 45 kilograms (100 pounds) per minute on a warmer day when the engine speed allows. The operating pressure of the air cleaner is near 2.11 kg/cm^2 (30 PSIG) and it is only used on the ground and at low altitudes (below about 2000 feet) since particulate matter is not present in significant concentrations at higher altitudes.

3.0 METHOD OF TESTING

3.1 Description of the Test Apparatus

A system closely duplicating conditions in the air cleaner and water separator was constructed at the Langley Research Center Flow Calibration Laboratory. The laboratory allowed set up of the

---

[2] Boeing Maintenance Manual/737 Aircraft. No. 21-51-0.

devices with provision to introduce samples and contain the carbon fibers. The air source was a 140 kg/cm^2 (2000 PSIG) compressed air line being expanded through a calibrated supersonic nozzle into the air cleaner or water separator. Nominal mass flow was available at ambient pressure and at a temperature of about 0° Centigrade as determined by the expansion. It was not considered necessary to match Reynolds numbers for the accuracy required in this experiment.

Figure 5 shows the test set up. The air entering the system could be controlled to better than .05 kilograms (0.1 pounds) per minute. Fibers were placed in the pipe between the two valves on the fiber injector. A sample of fibers, gravimetrically measured to the nearest tenth of a milligram was placed in the pipe and both valves were closed. Fibers were forced into the air flow by a separate air supply at a pressure slightly higher than that present in the straightening tube. The bottom of the fiber injector pipe had a 90° curve bend opening in the center of the straightening tube directing fibers downwind. The system was designed to disperse fibers and smooth out the air flow when it reached the test device.

Air flow was expanded at the rear of the air cleaner to enable capture of all fibers passing through the test device. The velocity of air in the straightening tube was about 46 meters/second (150 FPS) and was reduced to about 5 meters/second (15 FPS) at the exit filter. A brass sieve, of 1/3 mm mesh was placed in front of the exit filter to catch all fibers passing through the air cleaner or water separator. The sieve was 61 cm by 61 cm (24 inches by 24 inches) and was coated with filter coating oil, to make fibers adhere. To ensure no fibers passed into the room a 61 cm by 61 cm x 30 cm (24 inch x 24 inch x 12 inch) filter was placed behind the measuring sieve. After the test all fibers were removed from the wire mesh by repeated blottings with adhesive paper. The adhesive papers were then examined under a microscope to count and size the fibers.

3.2 Test Procedures

Unsized Thornel 300 fibers, manufactured by Union Carbide were used in all tests. The fibers were chopped to the test lengths of one, three or ten millimeters. Approximately 96% of the fibers chopped were of the desired length. This means that in testing with one millimeter fibers, 4% of the input fibers were of various lengths up to ten mm. Conversely when using ten mm fibers about 4% of the input was one to 9 mm in length. Graphite fibers are stiff and brittle and totally homogeneous test lengths are difficult if not impossible to prepare. It is believed this error is not significant in the results presented.

Three rates were chosen to forecast the effect of varying flow rates. A low flow rate of 18 kg/minute (40 PPM), an intermediate of 27 - 32 kg/minute (60 - 70 PPM) and a high rate of 40 kg/minute (100 PPM). Generally one test run was made at each fiber length and flow rate as shown in Figure 6 and 7.

Each test run lasted about fifteen minutes. The air flow was turned on and allowed to stabilize for two minutes. Fibers were injected in about three steps to avoid packing the fibers too tightly and induce clumping. After injection of the fibers the system was allowed to run for about five minutes to ensure all fibers were blown through. Indeed the high air flows in the straightening pipe, were effective in cleaning out the system and passing all the fibers through.

After each test the system was vacuumed and cleaned for the next test, the 1/3 mm mesh brass sieve was carefully removed and taken to the laboratory for counting. It was found that the fibers broke up at the high velocities because of impacts they were subjected to. At least eighty percent of the fibers out in every test were reduced to lengths of about one mm. This factor must be remembered in interpreting results as one ten mm fiber might be broken into ten one mm fibers.

4.0 DATA ANALYSIS

Figures 6 and 7 show the results of testing the Water Separator and Air Cleaner. The number of fibers out of all lengths greater than 1/2 mm is given with the transfer function. Only lengths greater than 1/2 mm were counted. Shorter lengths and dust were observed but are not reported herein. The transfer function is the number of fibers leaving the device divided by the number entering the device. The number of fibers in is calculated from: the density of Thornel 300 (T-300) fibers which is 1.80g/cc; the average diameter of T-300, 8 microns; and the length. The weight of the 1 mm long fiber is 9.0×10^{-8} grams.

Each sample of fibers was weighed on a balance to the nearest tenth of a milligram. Sample sizes ranged from .2000 grams to .6000 grams in weight. The number of fibers was found by dividing the sample weight by the weight of one fiber.

4.1 Test Analysis

Figures 6 and 7 show the test runs, flow rates, number of fibers in and numbers of fibers out of various lengths. Using the transfer function for the total fibers of all lengths yields the most conservative figure. This transfer function for 1/2 mm through 10 mm fibers is a conservative estimate if only 3 mm and longer are of concern. For these cases where 3-4 mm or 3-10 mm lengths are important the table values may be used directly. Figures 8 and 9 show plots of these data to depict trends in varying the air flow.

These plots show increasing transfer functions with increasing fiber lengths. Again, these trends are due to the breaking up of the longer fibers to produce more shorter fibers. One mm and 2 mm fibers were the predominant lengths in every output.

The water separator (Figure 8) showed a slight increase in transfer function with increased air flow. It is believed a transfer function of 1×10^{-3} may be used for 1 mm fibers in the spectrum of normal air flows. For 3 mm fibers a value of 7×10^{-3} presents a conservative value for all lengths and at 10 mm lengths 3×10^{-2} may be used. For cases where only fibers longer than 3 mm are important the transfer functions are less by about one order of magnitude.

The air cleaner showed only slight differences in transfer functions at one and three mm as shown in Figure 9. A value of 5×10^{-3} would be a conservative figure at these lengths across the spectrum of air flows. With ten mm fibers a value of 1×10^{-1} can be obtained as a conservative estimate. If one and two mm fibers are eliminated as being less of a hazard a conservative transfer function of 5×10^{-2} is indicated in the 3 - 10 mm column of Figure 7.

4.2 Error Sources

Errors in the experiment resulted from two major sources: estimate of the number of fibers injected and count of the fibers out. Fiber samples were weighed on a balance accurate to ± 0.3 milligrams. Fibers out counts were controlled by comparing fiber counts of different individuals on the same sample. One mm length tests in the water separator run at 32 kg/minute (70 PPM) and 45 kg/minute (100 PPM) were repeated to verify results (See Figure 8).

Initial tests were run using treated bridal veil as the fiber catching device. The mesh of the bridal veil was 1 mm and was not efficient in catching fibers shorter than 2 mm. Testing with bridal veil gave a transfer function an order of magnitude lower than those reported in Figures 6 and 7. The reported data is based on 1/3 mm mesh brass sieve material as the fiber catcher. It is believed that fibers 0.5 mm and larger were efficiently captured. Smaller particles (0.5 mm) were transmitted but not counted in the results as they were not considered electrically significant. To cause a short circuit with such short fibers would require a multi-fiber event only possible under exposures of a magnitude not expected in a fire release.

The impacts of fibers in the Water Separator and Air Cleaner caused fiber breakup so that at least 80% of the fibers out in each test run were 2 mm or less in length. The fiber injection part of the straightening tube was curved downwind to effect a smooth injection. Direct impact and major breakup occurred in the test devices. The bleed air ducts of an aircraft system should present a more effective fiber breaking environment than the straightening tube used in this test. Fiber breakup before reaching the test device was not considered a significant problem.

5.0 SUMMARY

5.1 The Water Separator

For inputs of 3 mm and shorter length fibers a transfer function of 7×10^{-3} may be conservatively used. Eighty percent of the output fibers will be less than 2 mm in length. For 10 mm fibers a transfer function of 5×10^{-2} may be conservatively used with 80% of the output fibers being less than 2 mm long. These values are conservative at all airflow rates from 18 to 45 kg/minute (40 to 100 PPM).

5.2 The Air Cleaner

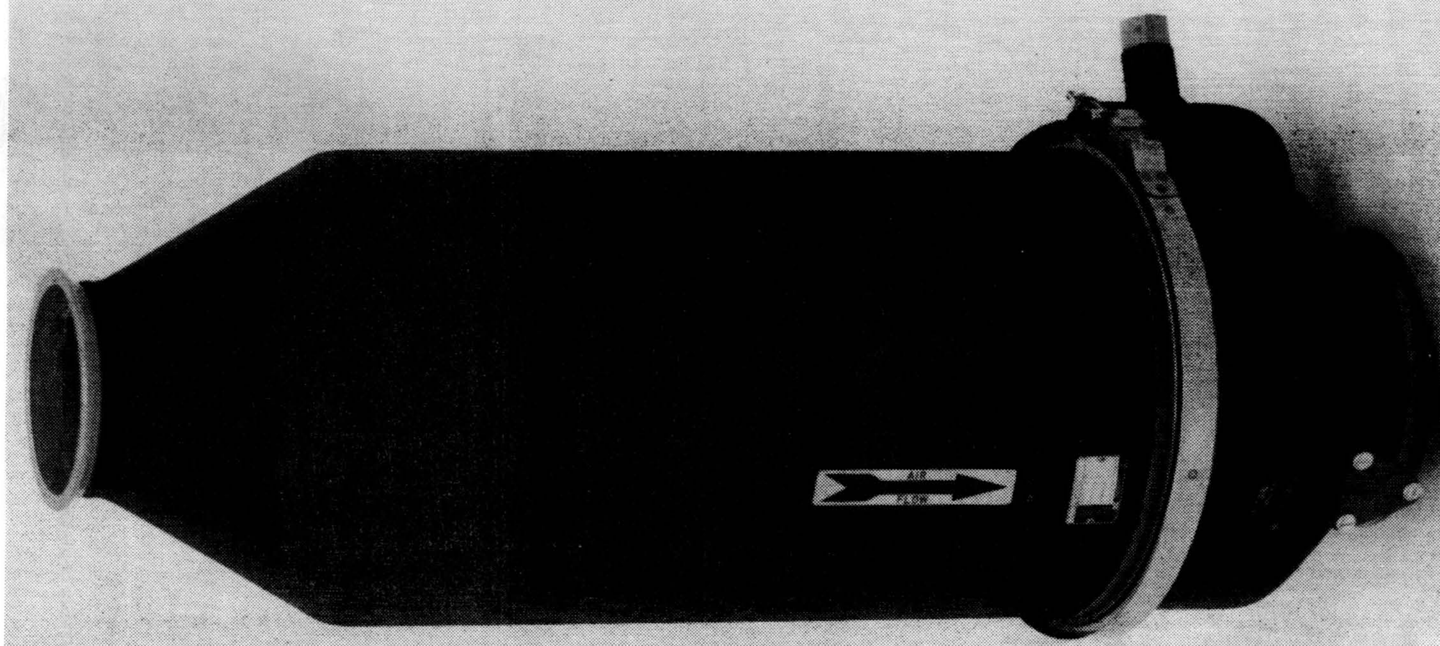
A transfer function of 5×10^{-3} may be used for all input fibers 3 mm long or less. The output will be 80% fibers less than 2 mm in length. A function of 1×10^{-1} may be conservatively used for an input of 10 mm long fibers with 80% of the output less than 2 mm long. These figures are conservative for air flows from 18 to 45 kg/minute (40 to 100 PPM).

5.3 Combined Filtering

A combination of the two devices should present a transfer function equal to the product of the two functions.

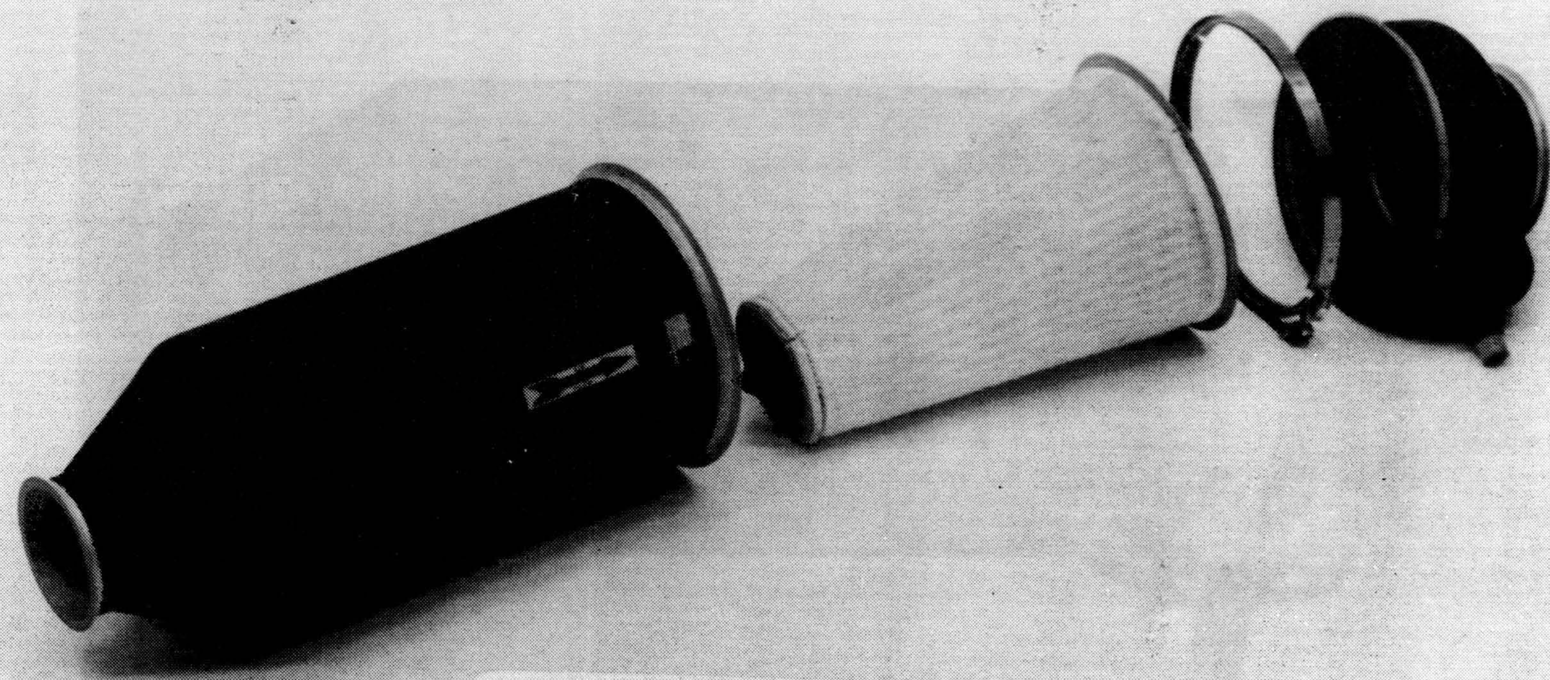
5.4 Conclusions

The Air Cleaner and Water Separator are effective filters of carbon fibers. If both devices are used and only fibers 3 mm and larger are considered a transfer function of $(5 \times 10^{-2}) \times (1 \times 10^{-1}) \times (.20) = 1 \times 10^{-3}$ is obtained.



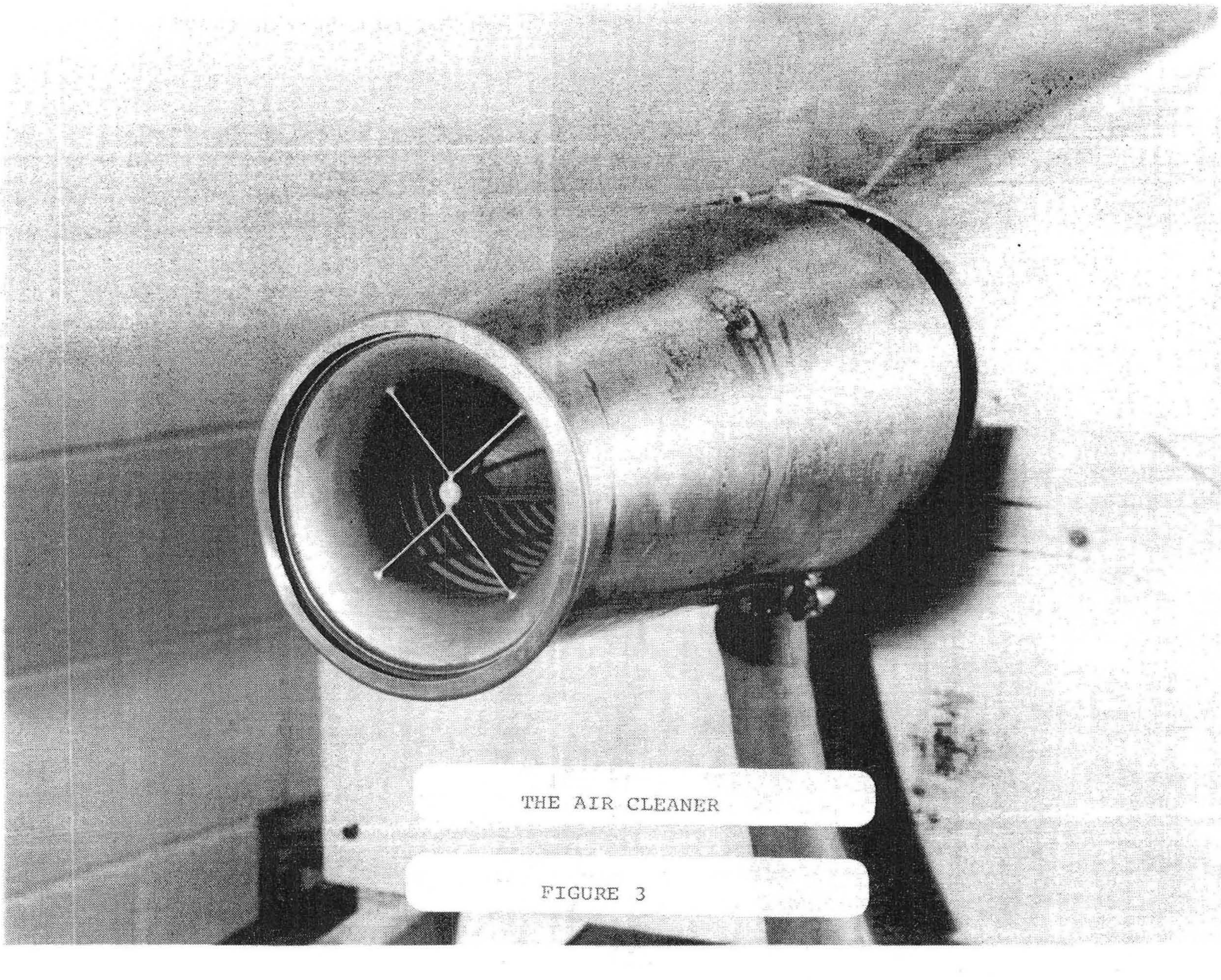
THE WATER SEPARATOR

FIGURE 1



EXPANDED WATER SEPARATOR

FIGURE 2



THE AIR CLEANER

FIGURE 3

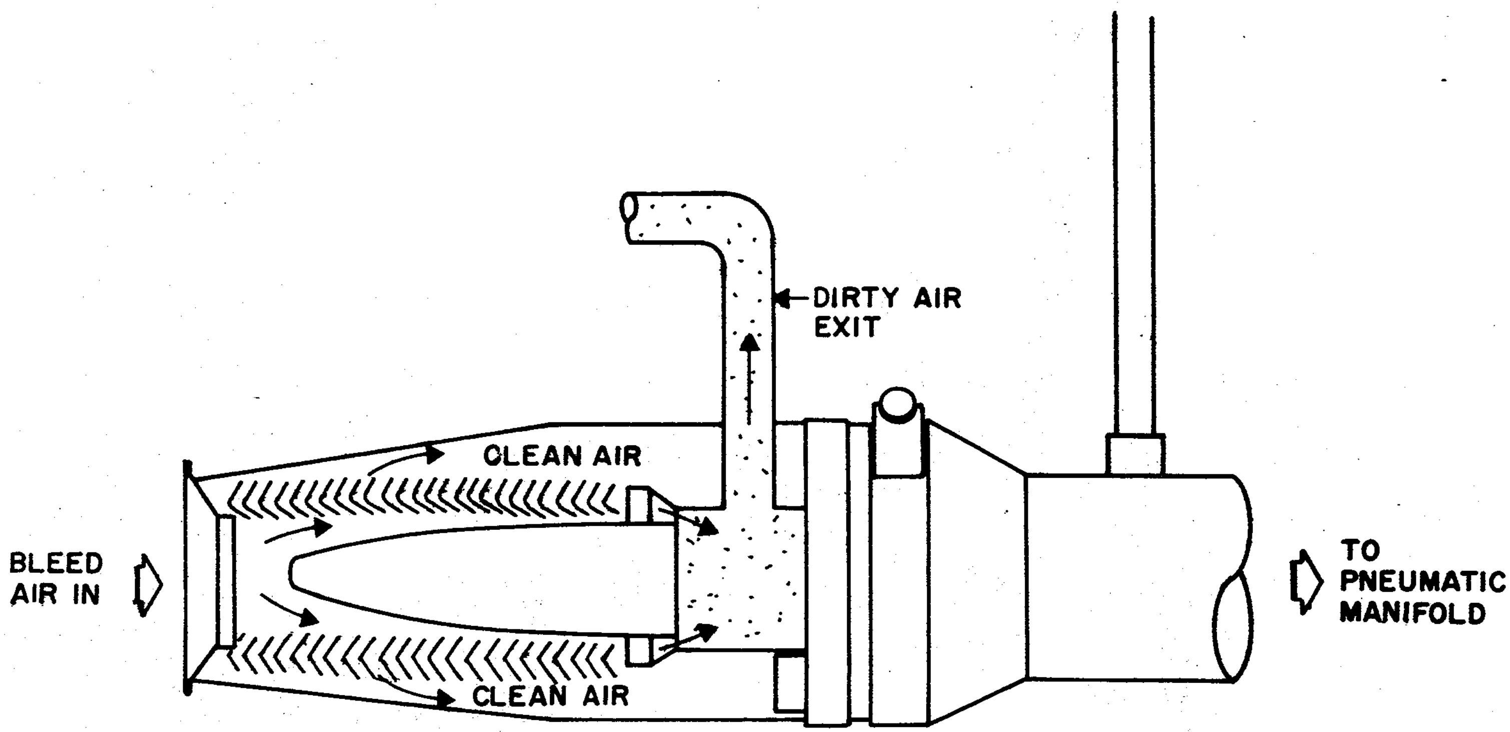
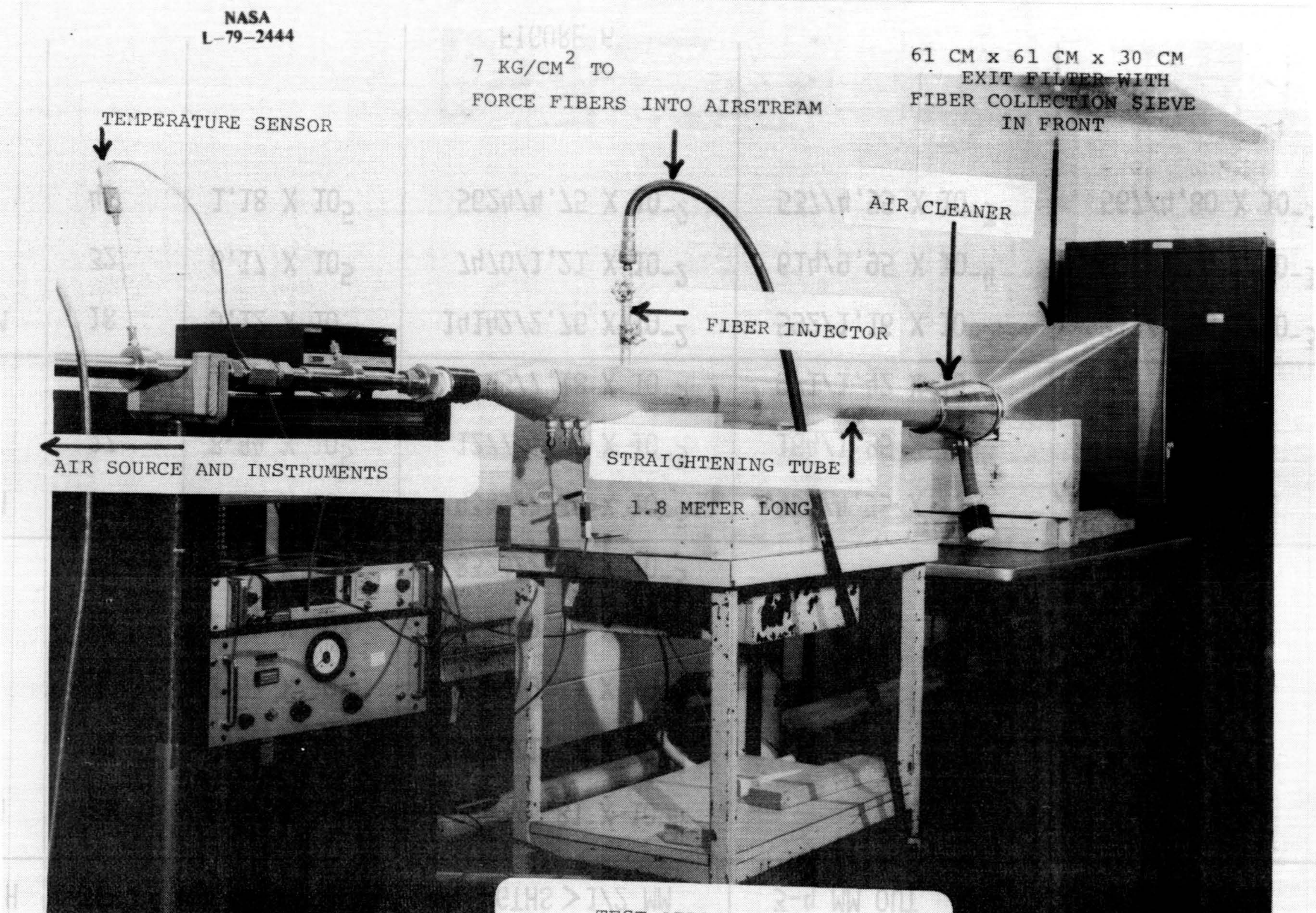


FIGURE 4: DIAGRAM OF AN AIR CLEANER



TEST APPARATUS

FIGURE 5

CARBON FIBERS PASSING THROUGH A TYPICAL WATER SEPARATOR

INPUT FIBER LENGTH	AIRFLOW KGMS/ MIN	NUMBER OF FIBERS IN	NUMBER OF FIBERS OUT/TRANSFER FUNCTION		
			TOTAL - ALL LENGTHS > 1/2 MM	3-4 MM OUT	3-10 MM OUT
1 MM	18	5.87×10^{6}	2242/3.81×10^{-4}		
"	32	7.35×10^{6}	10090/1.37×10^{-3}		
"	32	2.57×10^{6}	2505/9.73×10^{-4}		
"	45	2.64×10^{6}	2410/9.12×10^{-4}		
"	45	2.87×10^{6}	8323/2.90×10^{-3}		
3 MM	18	1.00×10^{6}	4349/4.34×10^{-3}	456/4.55×10^{-4}	
"	27	8.84×10^{5}	1277/1.44×10^{-3}	164/1.85×10^{-4}	
"	45	6.86×10^{5}	4923/7.18×10^{-3}	971/1.42×10^{-3}	
10 MM	18	5.12×10^{5}	14142/2.76×10^{-2}	592/1.16×10^{-3}	815/1.59×10^{-3}
"	32	6.17×10^{5}	7470/1.21×10^{-2}	614/9.95×10^{-4}	925/1.50×10^{-3}
"	45	1.18×10^{5}	5624/4.75×10^{-2}	537/4.55×10^{-3}	567/4.80×10^{-3}

FIGURE 6

CARBON FIBERS PASSING THROUGH A TYPICAL AIR CLEANER

INPUT FIBER LENGTH	AIRFLOW KGMS/MIN	NUMBER OF FIBERS IN	NUMBER OF FIBERS OUT/TRANSFER FUNCTION		
			TOTAL - ALL LENGTHS > 1/2 MM	3-4 MM OUT	3-10 MM OUT
1 MM	18	2.97×10^6	14632/4.93×10^{-3}		
"	32	6.09×10^6	8804/1.45×10^{-3}		
"	45	3.98×10^6	5088/1.19×10^{-3}		
3 MM	18	7.89×10^5	1583/2.01×10^{-3}	433/5.49×10^{-4}	
"	32	7.77×10^5	3984/5.13×10^{-3}	588/7.57×10^{-4}	
"	45	7.74×10^5	771/9.78×10^{-4}	102/1.32×10^{-4}	
10 MM	18	2.93×10^5	32655/1.11×10^{-1}	8576/2.93×10^{-2}	15898/5.43×10^{-2}
"	32	1.98×10^5	15648/7.90×10^{-2}	2390/1.21×10^{-2}	4647/2.34×10^{-2}
"	45	2.60×10^5	2131/8.19×10^{-3}	165/6.35×10^{-4}	454/1.74×10^{-3}

FIGURE 7

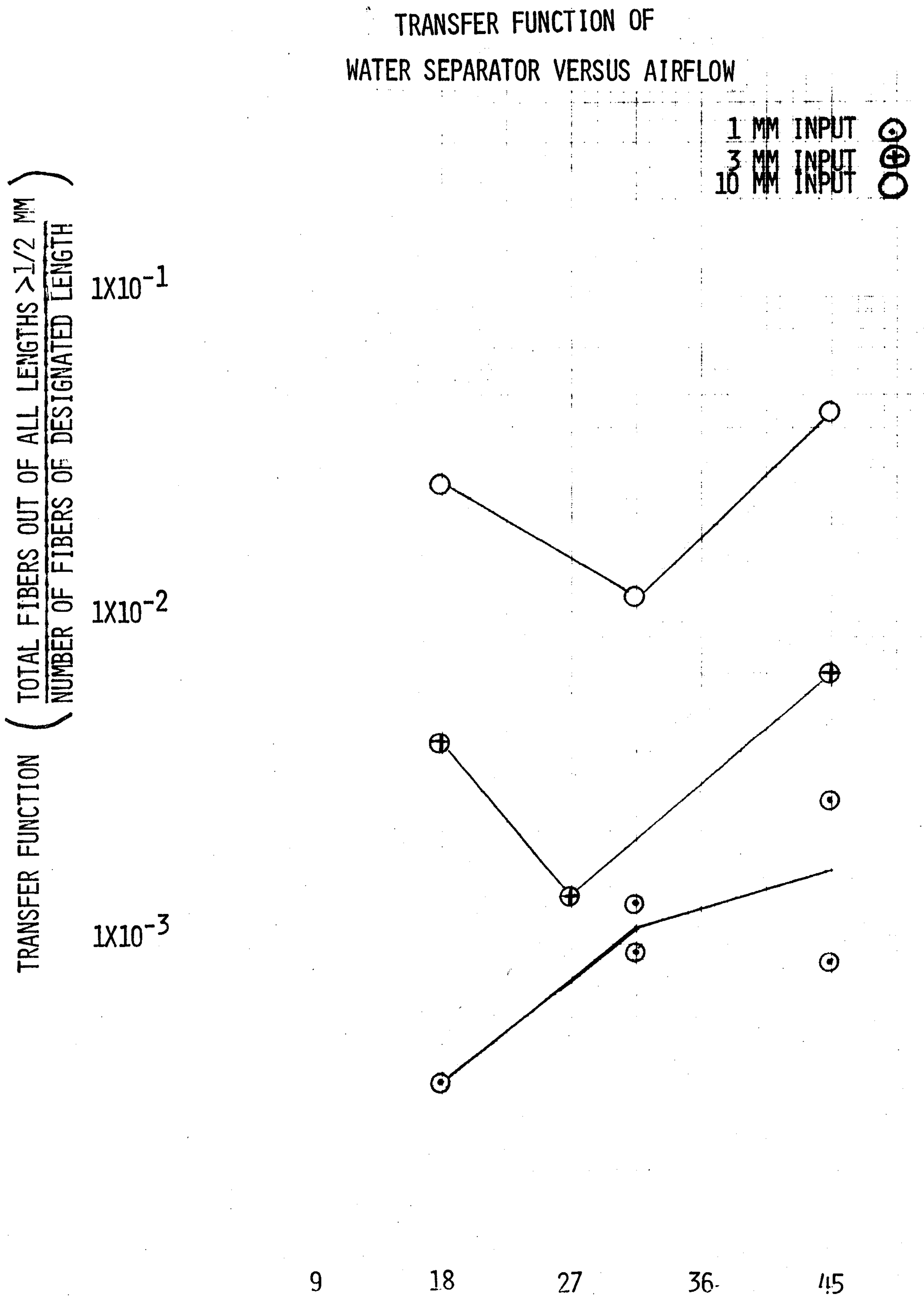


FIGURE 8: AIRFLOW IN KG OF AIR PER MINUTE/PPM

TRANSFER FUNCTION OF
AIR CLEANER VERSUS AIRFLOW

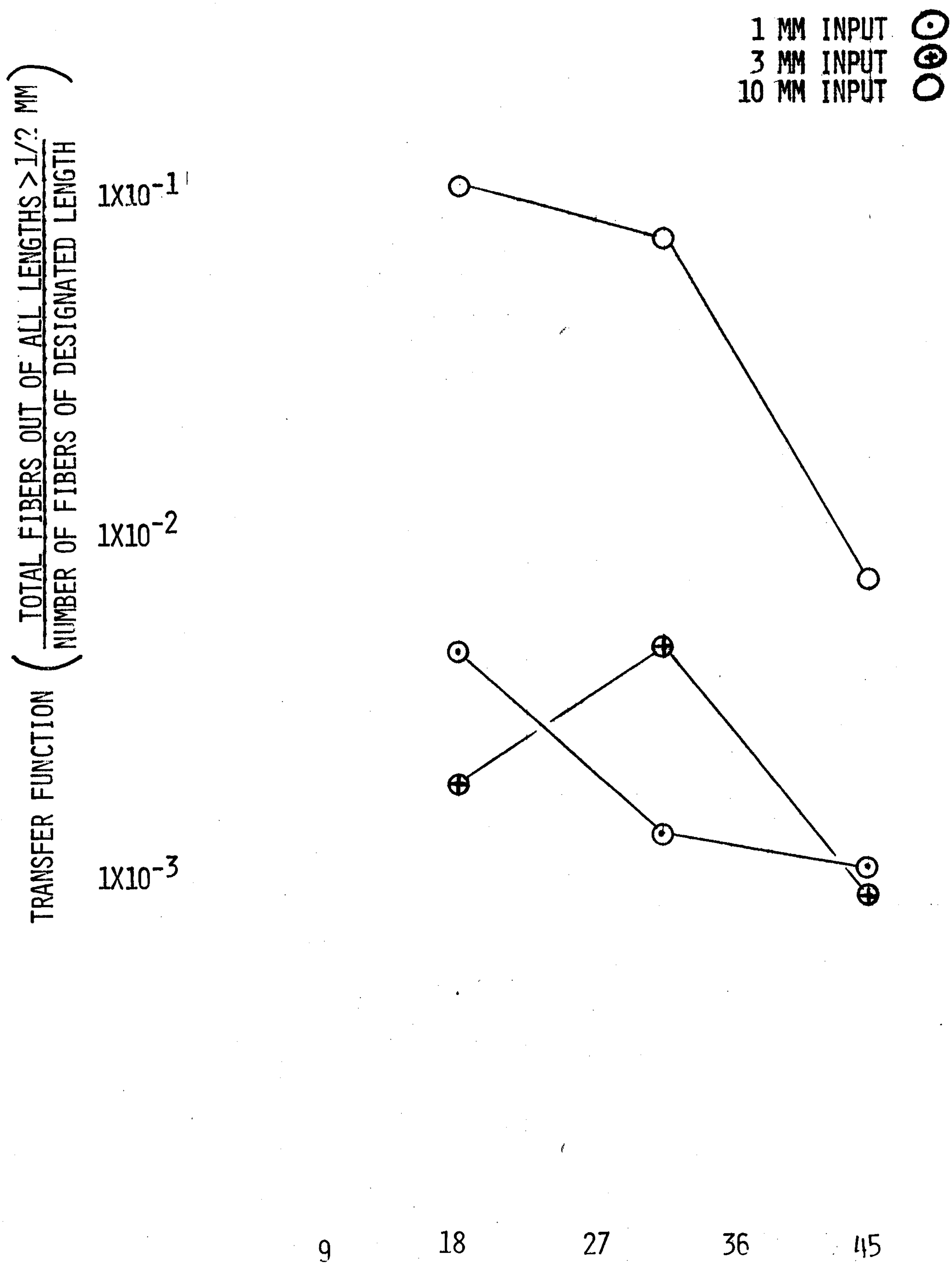


FIGURE 9: AIRFLOW IN KG OF AIR PER MINUTE/PPM