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TESTS FOR PARTICLE CONTAMINATION OF THE ENGINE INLET AIRFLOW FR--ETC(U)
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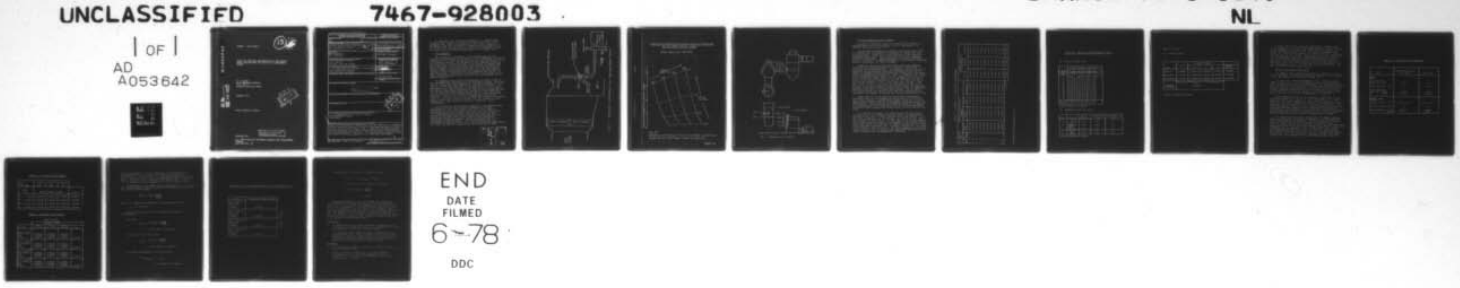

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TESTS FOR PARTICLE CONTAMINATION OF THE ENGINE INLET AIRFLOW FROM THE LACV-30 AIR MANAGEMENT SYSTEM

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Final Technical Report

Prepared For

U.S. ARMY MOBILITY EQUIPMENT RESEARCH AND DEVELOPMENT COMMAND
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Tests were conducted to demonstrate that the LACV-30 Air Management System removes at least 95 percent of the entering sand and dust. Analysis of 1-micron filters used in isokinetic sampling probes to measure entering and existing contamination levels indicated that the system removed 97 percent of the contamination entering during 22 minutes of vehicle operation in a high-sand environment.

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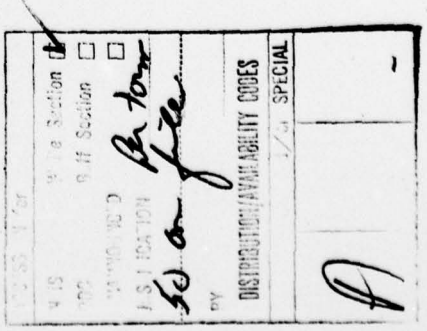
In compliance with Item 4b of Reference (a) - Modification Acceptance of "Changes to Statement of Work and Services" dated 12 August 1976, tests were conducted at Fort Story, Virginia on 23 November 1976 for the purpose of quantitatively validating that 95% of the sand introduced into the LACV-30 Air Management System is removed by the filtration system prior to the engine inlets.

Test Equipment

The contamination measuring system employed was the air sampling system described in Reference (b) for approximate isokinetic conditions at the engine plenum inlet and in the vertical duct of the air management system. The schematic of this sampling system and the carpet plot of probe flow rates as a function of engine horsepower conditions and internal probe diameter have been reproduced here in Figures 1 and 2 for convenience. The flow capacities of readily available vacuum pumps were such that 0.375 inch diameter stainless steel tubing with 0.035 wall thickness was selected to make four probes. Three probes are located at the entrance to the engine inlet plenum and one is located in the vertical AMS duct as shown in Figure 3.

The sampling probe system was fabricated and check tested by the Instrumentation Laboratory at Bell Aerospace Textron. The inlet ends of these probes were chamfered on the outside surface so as to present a relatively sharp edge to the airflow in the ducts. The anticipated duct flow velocities were calculated to be 63.4 fps at the inlet to the engine plenum and 67.4 fps in the vertical AMS duct for the prescribed engine operating condition of 1000 horsepower. For the four 0.375 inch diameter probes and the known vacuum pump capacities a probe flow velocity of approximately 65 fps was expected. In actual fact, the vacuum pumps were capable of producing probe flow velocities ranging from 53 to 55 fps during the tests, somewhat lower than those for isokinetic conditions, but not unacceptable.

The filters and filter holders employed in the sampling probe system were procured from Millipore Corporation, Bedford, Massachusetts. The filters were 47 mm (1.85 inch) diameter Fluoropore discs with 1.0 micron pore size (Cat. No. FALP 04700). Other MF-Millipore filters with 8 micron pore size were also purchased; but laboratory tests revealed a tendency for these to absorb more moisture from the air than the more hydrophobic Fluoropore filters and produced greater inconsistencies in the measurement of filter weights. The filter holders (Cat. No. xx43-04700) accomodated these filter discs and provided approximately 13.8 cm^2 (2.14 in^2) or 80 percent of the disc as filter area.



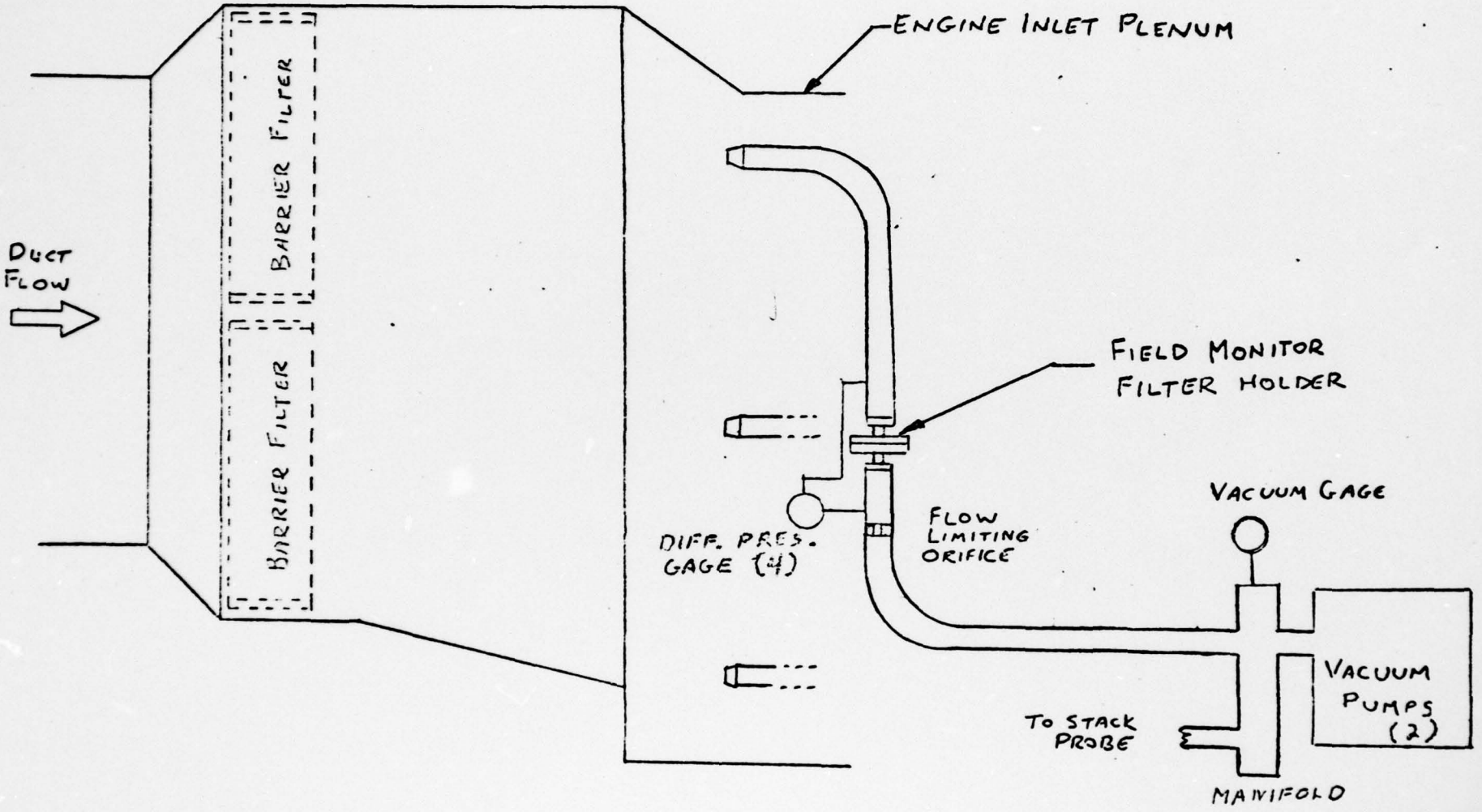


FIG 1 - SCHEMATIC OF TYPICAL FLOW SAMPLING PROBE SYSTEM

ISOKINETIC SAMPLING AT ENGINE PLENUM ENTRANCE OR AT AMS INTAKE STACK

FLOW VELOCITY = 65 FPS

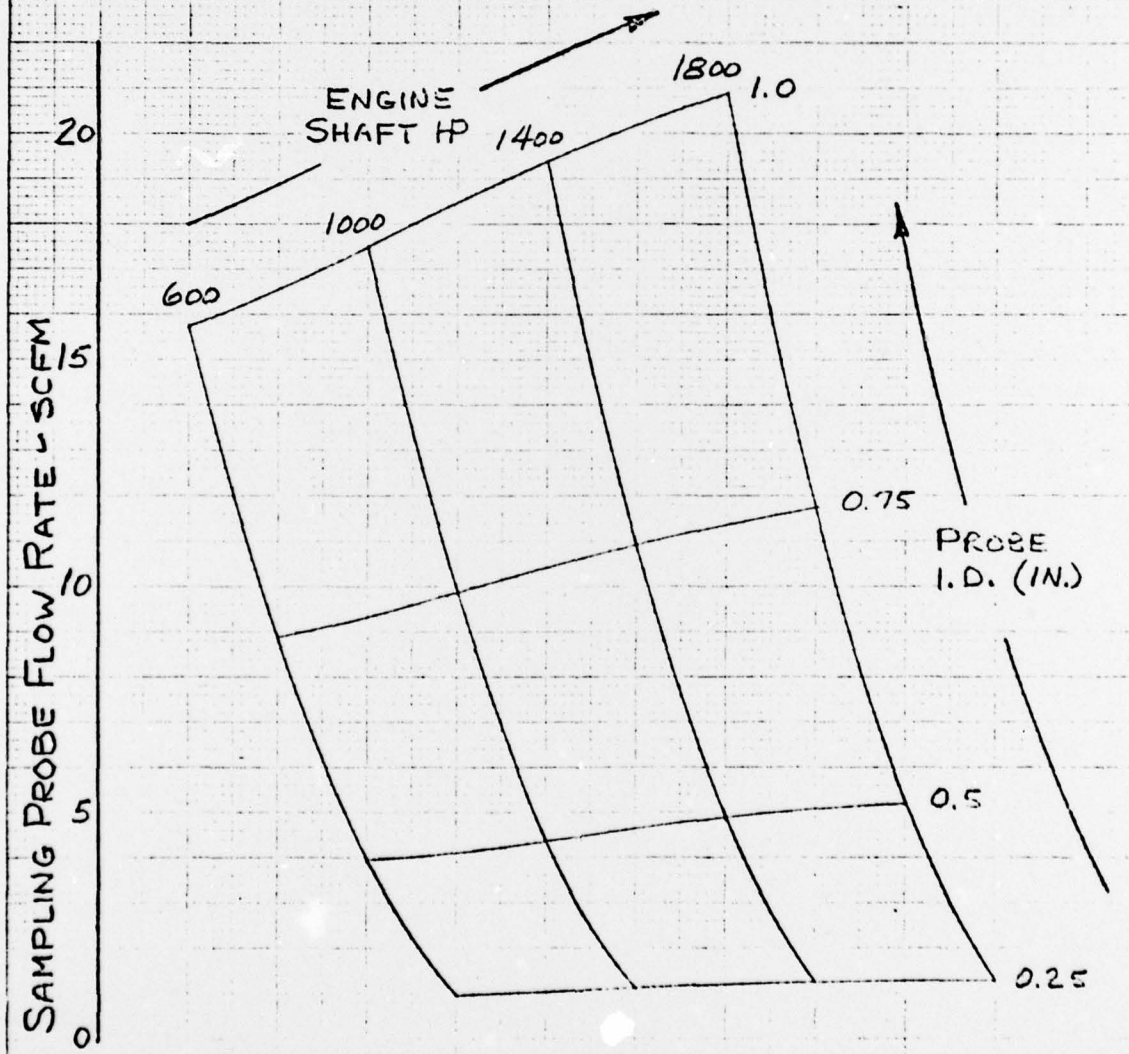


FIG 2-
VARIATION OF SAMPLING PROBE FLOW RATE WITH ENGINE SHAFT OUTPUT H.P. & PROBE INTERNAL DIAMETER

9/8/76 CFS

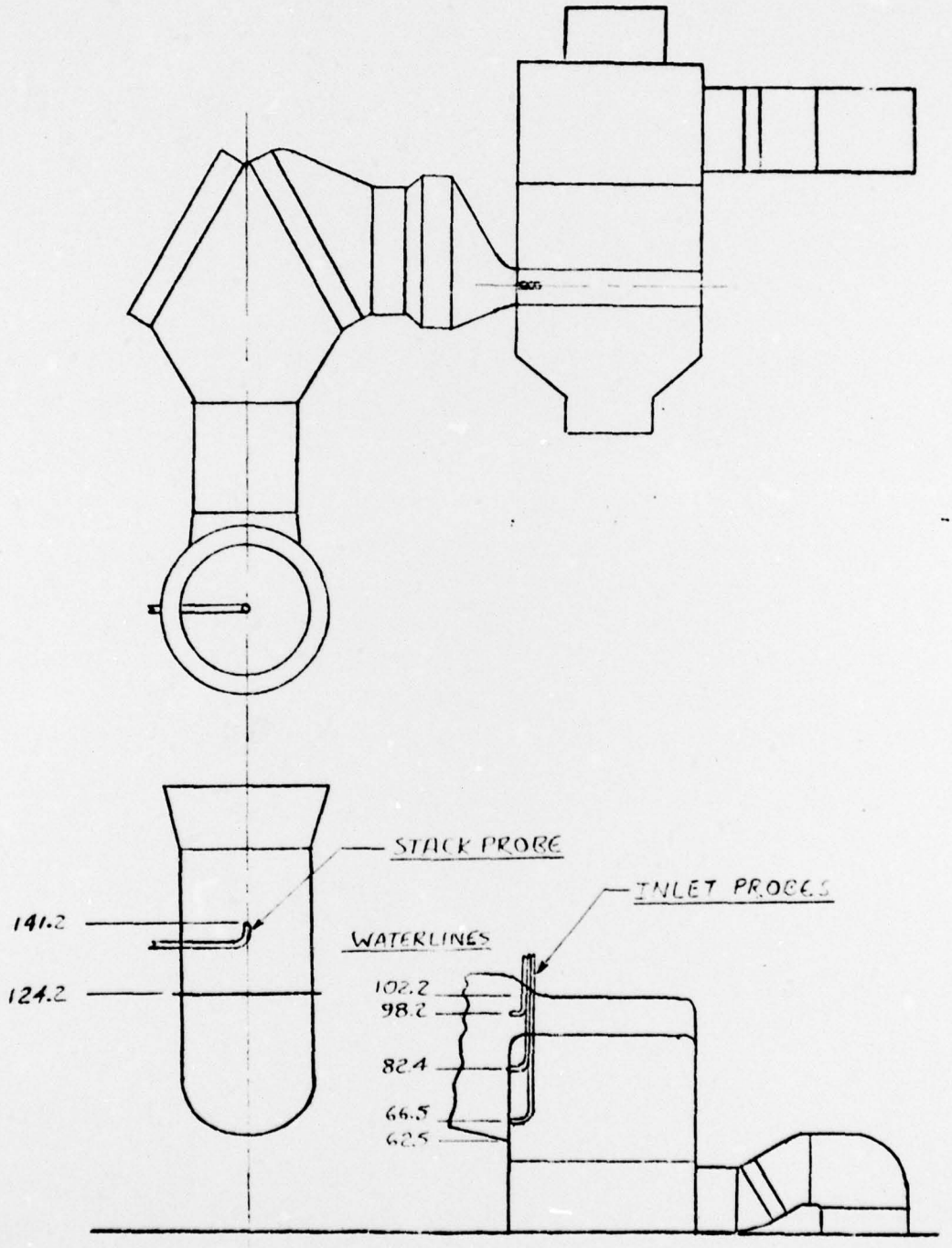


Fig. 3 Sampling Probe Locations

Pre-Test Sampling System Checkout

A series of laboratory tests were performed to evaluate the sampling probe system and establish the test techniques to be utilized during the vehicle tests.

The accuracy with which the weight of the filter discs could be determined was accomplished by weighing ten filters on three successive days. Except for the short period of time during the weighing process, these filter discs were stored in a dessicant controlled environment. The repeatability of results contained in Table I indicates a probable accuracy of filter weight measurement within ±0.25 percent, or ±125 micrograms.

Laboratory tests were performed during which the sampling system was run for approximately one hour while inducing the relatively clean laboratory air. The purpose of these tests was to determine the actual probe flow rates attainable as well as the change in pressure differential across the filters with time under these low contamination conditions. Table II summarizes the results of these sampling system checkout tests. During these tests, the filter disc in the middle probe (No. 2) was placed in the filter holder in the reverse orientation; that is, the face presented to the flow was opposite to that of the other three filters. From Table II(a), it can be seen that this orientation of the filter produced an initially slightly higher pressure drop, but that the increase in pressure differential with flow time was not appreciably different from that of the other three filters. For the sake of consistency during the vehicle tests, the four filters were all installed in the manner to produce the lower initial pressure drop.

Probe flow rates were measured periodically during these laboratory tests of the sampling system by means of a flow meter. Table II(b) contains a representative sample of one set of these measurements together with the corresponding calculated probe inlet flow velocity. These measured flow quantities were later employed in evaluating the total contamination in the inlet air management system and engine plenum inlet flows during the full scale LACV-30 tests.

As a matter of interest, the four filters used during these laboratory tests were weighed before and after the approximately one hour of run time. A fifth (control) filter was exposed to the same type of handling, but no airflow. The results of this check are contained in Table II(c). The four filters accumulated approximately seven times the weight of contaminant as the control filter even though the air induced into the sampling probes was the normal, relatively clean laboratory air. Obviously, particles of the order of one micron in size were present and being stopped by the filters. Similar results could be expected with this probe system during any tests conducted in an uncontaminated environment.

TABLE I. ACCURACY OF FILTER WEIGHT MEASUREMENT

FILTER NO.	MEASURED FILTER WEIGHT (GRAMS)				PERCENT DEVIATION FROM AVERAGE		
Date Rel. Hum.	11/2/76 46%	11/3/76 44%	11/4/76 43%	Average	11/2/76	11/3/76	11/4/76
1*	0.053149	0.053092	0.053080	0.053107	+0.079	-0.028	-0.051
2*	0.053335	0.053205	0.053261	0.053267	+0.128	-0.116	-0.011
3	0.053287	0.053177	0.053138	0.053201	+0.162	-0.045	-0.118
4*	0.051504	0.051274	0.051348	0.051375	+0.251	-0.196	-0.052
5*	0.049873	0.049447	0.049448	0.049589	+0.572	-0.286	-0.284
6	0.053945	0.053772	0.053733	0.053817	+0.238	-0.084	-0.156
7	0.053774	0.053611	0.053607	0.053664	+0.205	-0.099	-0.106
8	0.051903	0.051751	0.051797	0.051817	+0.166	-0.127	-0.038
9	0.052098	0.051889	0.051956	0.051981	+0.225	-0.177	-0.048
10	0.052482	0.052374	0.052382	0.052413	+0.132	-0.074	-0.059
				AVG.%	+0.216	-0.123	-0.092

*Filters Used During Craft Tests

TABLE II. SAMPLING SYSTEM LABORATORY TESTS

(a) Filter Pressure Drop

Probe	Filter Pressure Drop (PSI) 1	2*	3	4
Time	Engine Inlet Plenum Stack			
(min.)				
0	N.A. - Improper Pump Setting			
5	1.87	2.18	1.59	1.88
10	1.91	2.20	1.63	1.94
15	1.93	2.21	1.63	1.96
20	1.96	2.23	1.66	1.98
25	1.99	2.25	1.68	2.00
30	2.01	2.26	1.70	2.01
35	2.02	2.27	1.72	2.02
40	2.05	2.30	1.74	2.05
45	2.07	2.32	1.76	2.09
50	2.10	2.35	1.78	2.11
55	2.15	2.36	1.80	2.13
60	2.15	2.39	1.81	2.15
P & % Increase	0.28 15	0.21 10	0.22 14	0.27 14

*Filter Reverse in Holder

(b) Sampling System Flow Rates

Probe	Location	Filter ΔP(PSI)	Probe Flow (SCFM)	Probe Velocity (FPS)
1	Engine Plenum Bot.	2.18	1.65	54
2*	Engine Plenum Mid	1.91	1.68	55
3	Engine Plenum TOP	2.10	1.67	55
4	AMS Stack	2.36	1.63	53

*Filter Reversed in Holder

Table II (Cont.)

(c) Filter Weights

Probe	Weights (Grams)				
	1	2*	3	4	Control Filter
Pre-Test	0.054084	0.054761	0.055269	0.057160	0.049018
Post-Test	0.055766	0.056576	0.056903	0.058453	0.049239
Contaminate	0.001632	0.001815	0.001634	0.001293	0.000221
Average Contaminate	0.001594				

*Filter Reversed in Holder

A final check of the system was made wherein a small amount of sand obtained at Fort Story was purposefully introduced into one of the sampling system probes while monitoring the pressure drop across that filter and one other. The resulting pressure drop across the filter was not measurably different than that determined from the previous flow tests. Inspection of the filter showed that the larger particles had been thrown outward along the inside of the "O" ring which sealed the two halves of the filter holder together. This was undoubtedly due to the flow directing vanes molded into theinside of the inlet cap of the filter holder. This test was performed twice; once with the filter horizontal and once with it vertical, with similar results.

LACV-30 Fort Story Test Results

The sampling probe system was installed on LACV-30-1 at Fort Story, Virginia. The pertinent parameters employed in the analysis of the data obtained is contained in Table III.

The tests were conducted primarily on the overland training course at Fort Story. With the sampling probe system inoperative craft engines were started and accelerated to and maintained between 1000 and 1100 eshp. A sequence of slow maneuvers was then executed with the sampling system operating. The maneuvers were aimed at keeping the craft engulfed in the cloud of sand and dust disturbed by the efflux of air from the cushion. The craft was operated in this manner for a total time of approximately 22 minutes.

After shutdown upon return to the base, it was found that an inadvertent spillage of oil on the belts and pulleys of the vacuum pumps had caused some slippage at times during the tests. This resulted in a reduced vacuum being drawn on the sampling system and produced lower flow quantities and velocities in the probes. This condition equally affected the three engine plenum inlet probes and the single AMS stack probe. Since the important factor was the ratio between the contaminants collected on the filters in the engine plenum inlet probes and in the AMS stack probe, it was concluded that the data recorded would provide representative results.

The filters were carefully removed from the sampling system, packed in dust proof containers and shipped to the Bell Aerospace Textron Laboratories for analysis. The filter weights before and after the Fort Story tests were tabulated in Tables IV and V. Table IV contains the filter weight data recorded on three successive days prior to the tests, from which average clean filter weights were determined for the analysis. Table V contains the filter plus contaminant weight data after the tests for three weighings made after different lengths of storage times in a dessicant controlled atmosphere. Since the data show no consistent weight trend with storage time, the averages of these three weights were taken for

TABLE III. PERTINENT TEST PARAMETERS

ITEM	ENGINE PLENUM INLET (ONE SIDE)	AMS STACK
DUCTS		
Flow Area per Side (Sq. Ft.)	2.78	6.68
Flow Velocity (FPS)	63.6	67.4
Flow Quantity per Side (SCFS)	176.8	450.2
(SCFM)	10,609	27,014
PROBES (EACH)		
Flow Area (Sq. Ft.)	507.4×10^{-6}	507.4×10^{-6}
Flow Velocity (FPS)	55	53
Flow Quantity (SCFS)	0.02773	0.02713
(SCFM)	1.664	1.628

TABLE IV. PRE-TEST FILTER WEIGHTS

Date Rel. Hum.	11/2/76 46%	11/3/76 44%	11/4/76 43%	
Filter No.	Filter Weights (Grams)			Avg.
No. 1 (Inlet)	0.053149	0.053092	0.053080	0.053107
No. 2 (Inlet)	0.053335	0.053205	0.053261	0.053267
No. 5 (Inlet)	0.049873	0.049447	0.049448	0.049589
No. 4 (Stack)	0.051504	0.051274	0.051348	0.051375

TABLE V. POST-TEST FILTER WEIGHTS

(11/24 & 25/76)

	Weights (Grams)			
Filter	Pre-Dessicant	3 Hr. Dessicant	96 Hr. Dessicant	Avg.
No. 1 Inlet				
Filter+Dish	1.453968	1.454041	1.454339	
Dish	1.398839	1.398839	1.398839	
Filter	0.055129	0.055202	0.055500	0.055277
No. 2 (Inlet)				
Filter+Dish	1.445207	1.445177	1.445021	
Dish	1.390888	1.390888	1.390888	
Filter	0.054319	0.054289	0.054133	0.054247
No. 5 (Inlet)				
Filter+Dish	1.443630	1.443605	1.443480	
Dish	1.392289	1.392289	1.392289	
Filter	0.051341	0.051316	0.051191	0.051283
No. 4 (Stack)				
Filter+Dish	1.487280	1.487919	1.487801	
Dish	1.395352	1.395352	1.395352	
Filter	0.091928	0.092567	0.092449	0.092315

use in the analysis. Table VI tabulates the average weight of contaminant collected on each of the four filters during the LACV-30 tests. The three from the engine plenum inlet probes have been averaged to yield a value of contamination weight of 0.001615 grams. The filter from the probe in the vertical duct (stack) of the Air Management System accumulated a total of 0.040940 grams.

Determination of the representative contamination in the overall duct flow determined from these probe filter values was made using the following relationship:

$$W_{duct} = W_{probe} \frac{Q_{duct}}{Q_{probe}}$$

Where: W = weight of contaminant in a given length of time

Q = air flow rate

Values from Tables III and IV produced the following contamination:

AMS Stack

$$W_{Stack} = 0.040940 \times \frac{27014}{1.628}$$

$$= 678.3 \text{ grams in 22 minutes}$$

Inlet to each Twin Pack Plenum

$$W_{Inlet} = 0.01615 \times \frac{10609}{1.664}$$

$$= 10.30 \text{ grams in 22 minutes}$$

The total contamination to both Twin Packs:

$$W_{Inlets_{total}} = 2 \times 10.3$$

$$= 20.6 \text{ grams in 22 minutes}$$

TABLE VI. POST-TEST MINUS PRE-TEST (FILTER CONTAMINATION)

Filter	Averaged Weights (Grams)
No. 1 (Inlet) Post-Test Pre-Test Residue	0.002170
No. 2 (Inlet) Post-Test Pre-Test Residue	0.000980
No. 5 (Inlet) Post-Test Pre-Test Residue	0.001694
No. 4 (Stack) Post-Test Pre-Test Residue	0.040940

Average 0.001615

Contamination removed by the filtration system

$$W_{Stack} - W_{Inlet_{Total}} = W_{removed}$$

$$678.3 - 20.6 = 657.7 \text{ grams in 22 minutes}$$

$$\text{Percent Removed} = \frac{657.7}{678.3}$$

$$= 97.0\%$$

Microscopic inspection of filter number one revealed a concentration of 10 micron sized particles at the pore areas of the filter. Scattered over the remaining area were particles larger than 10 microns. The majority of these were in the range of 20 to 100 microns. There were also a few irregular shaped particles, apparently grains of sand, in the 350 micron size range. Since the barrier filter is designed to prevent the passage of this size particle, they must have entered the duct system through undetected holes or cracks or been introduced to the system when it was opened for routine maintenance.

CONCLUSIONS

1. The quantitative test results show that 97 percent of the sand and dust entering the LACV-30 Inlet Air Management System was removed by the present filtration system.

2. Some particles larger than 10 microns were detected at the engine plenum inlet. Since the barrier filter cannot pass particles of this size, steps should be taken to better seal the duct system against inadvertent entry of sand and dust around and/or downstream of the barrier filter.

REFERENCES

(a) Modification No. P00009 to Contract No. DAAK02-75-C-0149, dated 14 September 1976.

(b) "Work Statement for Validation of the Sand Filtration Effectiveness of the LACV-30 Air Management System" Attachment to 12 November 1976 BAT Letter to U. S. Army MERADCOM from C. E. Burr.