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Technical Report

No. 13203 Addendum

EVALUATION OF ULTRA FINE METAL
MESH FILTER MEDIA IN PLEATED
CONFIGURATION FOR APPLICATION
TO AIR FILTERS FOR DIESEL AND
TURBINE COMBAT VEHICLES:

ADDENDUM

FEBRUARY 1987

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1.0 INTRODUCTION

An experimental air filter for the Army's 2½ ton truck with a metal mesh media has been successfully tested in the test facility of Fil-Tech Systems, Inc. This testing was the third project in a program to develop a self cleaning air filter employing a shock wave cleaning system for the US Army TACOM. A self cleaning metal mesh air cleaner is of interest for military vehicle applications because it has the potential of eliminating the structural and operational failures of conventional replacable air filters. These filter failures have resulted in catastrophic engine damage that is both expensive and operationally unacceptable. These failures are due to the relative fragility of the conventional filter media and improper installation of the filters during their frequently required changes. The metal mesh is extremely strong and durable. A shock wave cleaned metal mesh air filter would be permanently installed at the time the vehicle is constructed and will probably out last the vehicle. The shock wave cleaning system will clean the filter in place thus eliminating the exposure to failure during the filter changes that are required with the conventional filters.

The principles of the shock wave cleaned metal mesh media filters and their durability have been proven in a variety of industrial applications. These filters have been in continous service for several years. Space is much more limited in the vehicle application than it is in the industrial application. The current projects in the TACOM Metal Mesh Filter program are to generate the data needed to design the compact system needed for the military vehicle application.

The projects conducted to date have been to obtain a clear understanding of the characteristics of the metal mesh media. In the first project conducted under contract DAAE07-82-C-4120, the performance characteristics of the metal mesh media in the flat configuration were determined by testing and then related analytically to the weave of the media. In the second project under contract DAAE07-82-C-R120, selected media were tested in the pleated configuration and an analytic model of their capacities was developed. As a part of the second project, two full scale metal mesh filters were constructed for TACOM testing and demonstration. These filters were constructed by replacing the media in two standard filters for the U.S. Army's 2½ ton truck with

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metal mesh media. These filters exceeded the size that could be accommodated in the Fil-Tech test facility. In accordance with the contract they were delivered to TACOM without testing so that the testing could be completed at the TACOM test facility. The Army testing indicated that the pleats in the filter collapsed on one another and thus blocked the flow thru the filter. TACOM then issued Mod P00002 to contract DAAE07-84-C-R015 for Fil-Tech Systems Inc. to:

1. modify its facility to accept the 2½ ton truck filter housing and increase its capacity to allow testing of the 2½ ton truck's filter system,
2. to add a support system for the filter media to prevent the pleat collapse,
3. to functionally test the filter modification in the Fil-Tech facility,
4. to prepare a letter report outlining the results of the testing.

The required modifications were made to the filters and the test facility, and the testing was performed as prescribed by Fil-Tech Systems under the direction of TACOM personnel. The test data was very limited and it was found that an extensive analytic effort would be required to properly interpret the data. Fil-Tech had developed the required analytic capabilities in previous air filtration work. This analytic effort was clearly beyond the scope of the contractual obligations under Mod P00002, but was performed in order to assure that the implications of the test results would be properly understood. This report contains the results of this testing and analysis.

2.0 RECOMMENDATIONS

1. Development of the shock wave cleaning device for the metal mesh filter should proceed.
2. The Fil-Tech Systems Inc. test facility should be applicable to a broad spectrum of air filter testing for TACOM.
3. Fil-Tech Systems Inc.'s analytic capability should be applied to a broad range of air filtration problems for TACOM.

3.0 CONCLUSIONS

1. Metal mesh media are practical for air filters for military vehicles.
2. An air filter with a metal mesh media for the U.S. Army's 2½ ton truck has been tested and demonstrated:
 - a. the test filter will have a capacity of 1.41 kg of dust and a life of 3.8 hours in a proper filter housing when tested with the Army's standard test cycle,
 - b. and the test filter will have a capacity of 1.83 kg of dust and a life of 4.9 hours with a refined media support structure when tested with the Army's standard test cycle.
3. The capability of the Fil-Tech System Inc. test facility to test full scale truck filters has been demonstrated.
4. Fil-Tech System Inc.'s analytic capability to analyze pleated filters has been demonstrated.
5. Fil-Tech System's Inc. now has a thorough understanding of the characteristics of metal mesh media for air filters.

4.0 TEST

4.1 TEST APPARATUS

The test section of the test system was replaced with a 2½ ton truck filter housing and a higher capacity blower was installed. Other than these two modifications, the test apparatus was as described in References 1 and 2. The operating procedure was unchanged for that described in Reference 1 and 2.

The test filters were constructed by replacing the media of two standard 2½ ton truck filters with metal mesh media. This was done as part of contract DAAE07-84-C-R015. It is described in detail in Reference 3. Under modification P00002, corrugated spacers were installed in the pleats on the clean air side of the filter to prevent the pleats from collapsing on one another.

The primary characteristics of the test filter elements are tabulated on Table 4.1-1.

Table 4.1-1 Physical Characteristics of Test Filter Elements

Effective Filter Area	2.08 m ²
Number of Pleats	90
Pleat Depth	6.35 cm
Pleat Inlet	18.2 cm x .69 cm
Media Material	stain. steel metal mesh
Wire Spacing	260 x 1550 wires/in
Weave	Dutch Twill Weave

4.2 FILTER ELEMENT TEST

The test of the demonstration element was conducted on May 5, 1986 under the direction of Mr. Ghasson Kahlil and Mr. Mike Richards of TACOM. The test cycle used was prescribed by TACOM and is the test cycle used for acceptance testing of the Army's 2½ ton truck filters. This test cycle is tabulated on Table 4.2-1. The U.S Army requires that its filters have a duration of 3.5 hours or a capacity of 1291.5 grams when tested with this test cycle. They desire a duration of 5 hours or a capacity of 1850 grams. Also, they require that the initial restriction be less than 2239 Pa but desire that it be less than 1244 Pa.

The operating procedure was that described in References 1 and 2. The test was terminated after 30 minutes because the restriction exceeded 4978 Pa. The filter was partially cleaned by rapping and the second half of the test cycle was completed. The results of the test are presented on the test log which is reproduced as Figure 4.2-1 of this report. The data at the .193 m³/sec flow rates is presented graphically on Figure 4.2-2.

Table 4.2-1 Test Cycle

<u>Time, s</u>	<u>Flow Rate, m³/s</u>
0-10	.193
10-20	.116
20-30	.039
30-40	.155
40-50	.116
50-60	.077

- dust concentration: .883 g/m³
- A.C. coarse dust
- cycle repeated until pressure loss reaches 4978 Pa

METAL MESH FILTER ELEMENT TEST LOG

CONTRACT DATA 07-04-C-R015-P00001

Test No. 2 Date 5-16-86 Filter Weave 260 x 1550 Supplier Tylinter

Inlet Temp. (°F) 60 Barometric Pressure (in. Hg.) 29.82 Rel. Humidity (%) 75

Filter Area (Sq. Ft.) 20.87 Test Dust: A.C. Coarse

Pressure Drop Across Filter After Test (In. W.G.) 28.00 @ 410 cfm.

Pressure Drop Across Filter Before Test (In. W.G.) 8.80 @ 410 cfm.

Pressure Drop Across Filter After Cleaning (In. W.G.) 8.85 @ 410 cfm.

Pressure Drop Across Air Filter Housing (In. W.G.) 7.00 @ 410 cfm.

Air Flow CFM.	Dwyer Set Point In. W.G.	Dust Feeder Set Point	Dust Feed Rate Grams/Min.	Air/Filter Ratio
410	4.40	371	10.25	19.64 : 1
246	1.40	253	6.15	11.79
82	0.15	140	2.05	3.93 : 1
328	2.70	312	8.20	15.72 : 1
164	0.65	195	4.10	7.86 : 1

Time Min.	Pressure Drop IN. W.G. Flow 410 cfm	Pressure Drop IN. W.G. Flow 328 cfm	Pressure Drop IN. W.G. Flow 246 cfm	Pressure Drop IN. W.G. Flow 164 cfm	Pressure Drop IN. W.G. Flow 82 cfm
0	8.80				
10	20.20				
20			9.80		
30	21.60 *				2.55
40		16.75			
50			11.30		
60	25.10			7.00	
70	28.00 **				
80					
90					

* Rapped filter housing 3 times with a hammer, the pressure drop changed from 21.60 In. W.G. to 12.20 In. W.G.

** Rapped filter housing 3 times with a hammer, the pressure drop changed from 28.00 In. W.G. to 12.75 In. W.G.

Figure 4.2-1 Metal Mesh Filter Element Test Log

AIR CLEANER DUST CAPACITY AND EFFICIENCY AIR CLEANER TEST CODE SAE J726c Part 3: Industrial Air Cleaners

AIR CLEANER DESCRIPTION

ITEM MODEL/PART NO.

Assembly 2.5 Ton Truck
Precleaner none
Primary Element Pleated Metal Mesh
Secondary Element none

Mfg. Fil-Tech Exp. Element
Type Military Truck
Test Flow .193 m³/sec. scmh
Scavenge Air Flow _____ %
Dust Cup Unloader Valve

TEST CONDITIONS AND RESULTS

Initial Efficiency _____ %
Test Dust Fine Batch
Dust Fed 184 g
Initial Restr/Press. Drop 2.19 kPa
* Final Restr/Press. Drop 4.98 kPa
Relative Humidity 75 %
Temperature 15.56°C

Dust Capacity 91 g @ .193 m³/sec
Test Dust A.C. Course Batch _____
Concentration .833 g/m³
Accumulative Eff. _____ %
Precleaner Eff. _____ %
Dust cup serviced _____ times

* Army Spec for 2.5 Ton Truck

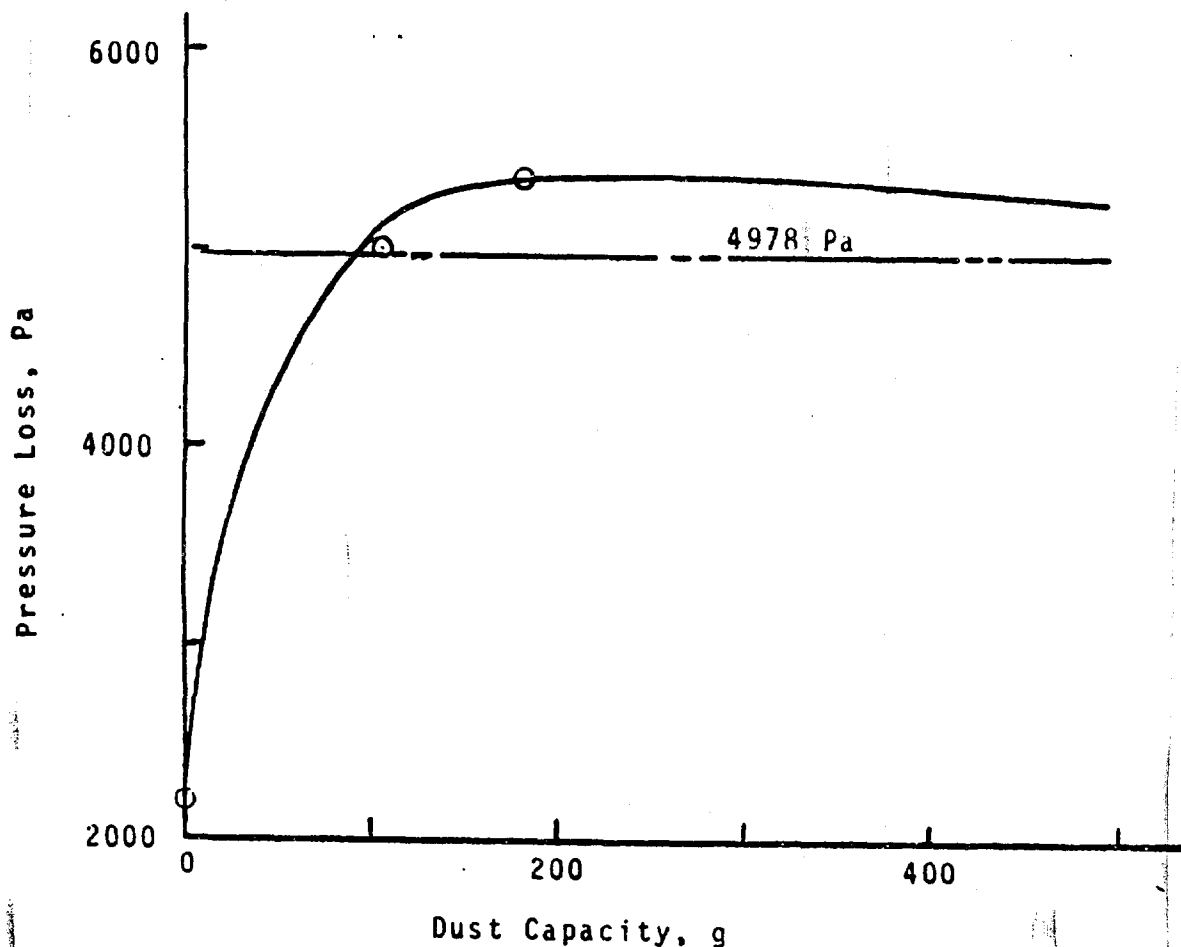


Figure 4.2-2 Metal Mesh Air Cleaner Dust Capacity

5.0 ANALYSIS

The data obtained in the first 30 minutes of the test were analyzed with the analytic model described in Reference 2. The data for the second 30 minutes could not be used because the partial cleaning introduced a degree of randomness into the dust mat that rendered it unusable for correlation with the analytic model. The analysis indicates that the high restriction, early in the test cycle, was due primarily to the non-uniform flow to the filter caused by mutual aerodynamic interference effects between the filter and the housing. There was no baffling or distribution system within the housing. The passage between the periphery of the element and the housing of the 2½ ton truck filter system determines the distribution of the air to the filter. The pleats act as aerodynamic vanes and initially direct the flow mainly into the pleats directly in front of the inlet to the housing. As the restriction builds up due to the dust collected in the pleats directly in front of the inlet, more air is diverted into the adjacent pleats. This process continues until all of the pleats around the periphery of the filter element are filled. Initially the pressure rises rapidly as the first pleats are filled with dust. After they become plugged, they behave as deflectors and the pressure remains constant or declines as the air is diffused around the filter element. This problem is compounded by an increase in blockage with pressure at the corrugated pleat supports. The pleat supports have rather large radiuses of curvature where they contact the medium. As the pressure increases, the medium is forced down into the space between the corrugations and over the surfaces of contact. This reduces the area available for free air flow through the medium. It was found that the area reduction due to mutual interference effects is described well by the expression

$$n_0 = 90 - 70.1 \exp(-1.41 M_d) \quad (1)$$

where:

- n_0 = effective number of pleats exposed to the air flow
- M_d = mass of dust in the filter, kg

and the area reduction due to compression at the supports is described well by the expression

$$\frac{A_{fc}}{A_f} = \exp(-1.08 \times 10^{-9} P_f) \quad (2)$$

where:

- A_{fc} = actual filter area available for
air flow
- A_f = total filter area exposed to the
air flow
- P_f = pressure loss across filter, Pa

These equations were used with the analytic model of Reference 2 to generate the performance curve plotted on Figure 4.2-2. The data correlation with the analytic model incorporating Equations 1 and 2 is presented on figure 5.0-1. Equations 1 and 2 are also presented graphically on Figure 5.0-2. By inspection of Figure 5.0-1 it can be seen that the correlation between the data and the analytic model is very good. The data points were plotted on this chart by assuming that the pressure measurements and masses were correct. For perfect correlation, the points would be at the intersections with the flow rates for the data. The deviation is the error. It can be seen that in all cases this error is well within the accuracy of the pressure measurements.

The analytic model was then used to estimate the pressure losses at higher filter dust loading. These results are presented on Figure 5.0-3. The fact that the corrections for mutual interference effects is bounded at 90 pleats and the corrections for compression effects is within the pressure range of the experimental data attests to the accuracy of these estimates. The performance with the interference and compression effects eliminated was also estimated. These results are also presented on Figure 5.0-3. It will be noted that if both area limiting effects are eliminated, the capacity if the system will be 1.83 kg in the government test. This is the capacity desired by TACOM. If only the interference effects are eliminated, the capacity will be 1.41 kg. If only the compression effects are eliminated, the capacity will be 1.55 kg but the pressure loss in the early stages, while less than the specified limit, will be unacceptability high.

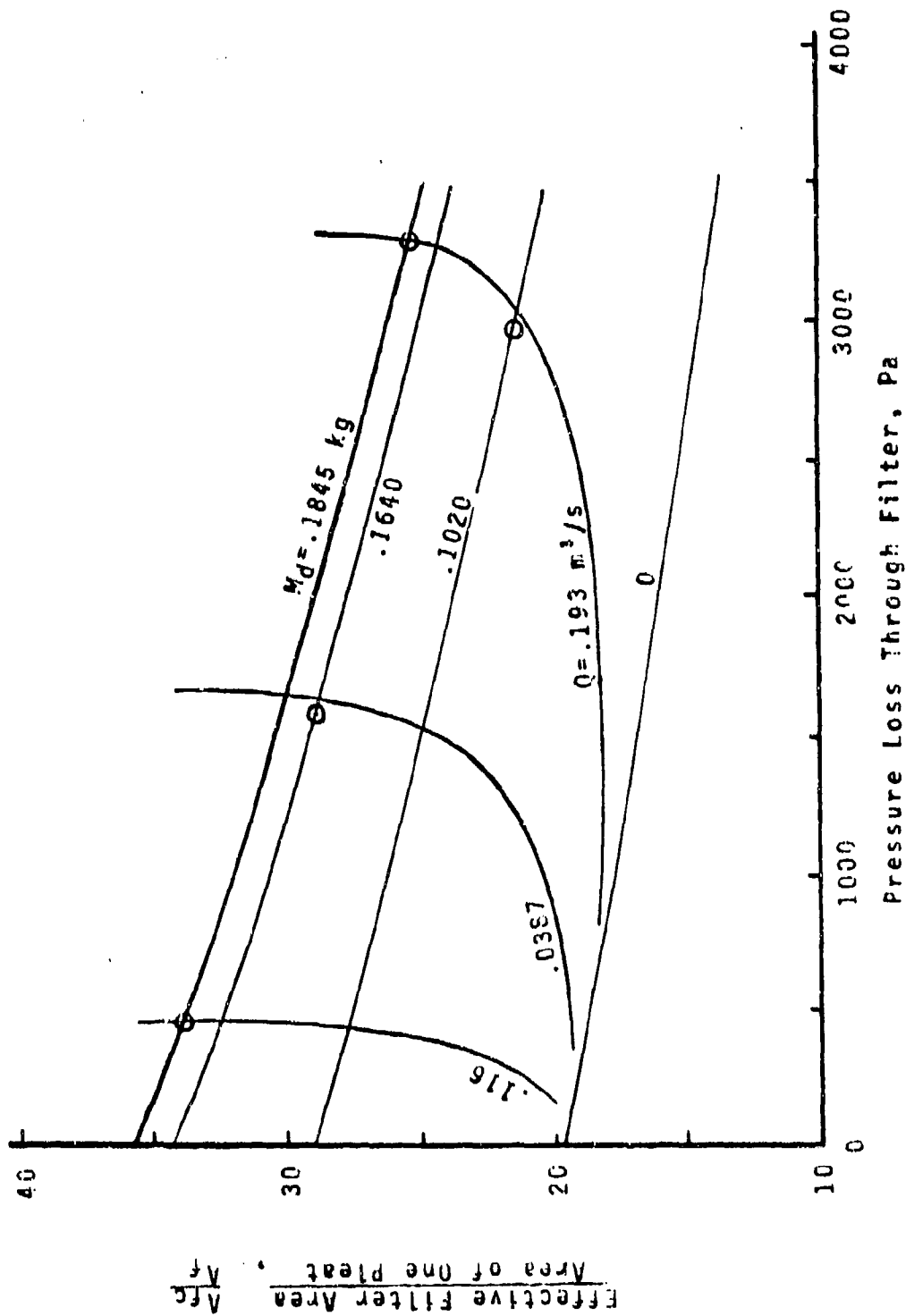


Figure 5.0-1 Data Correlation with Analytic Model

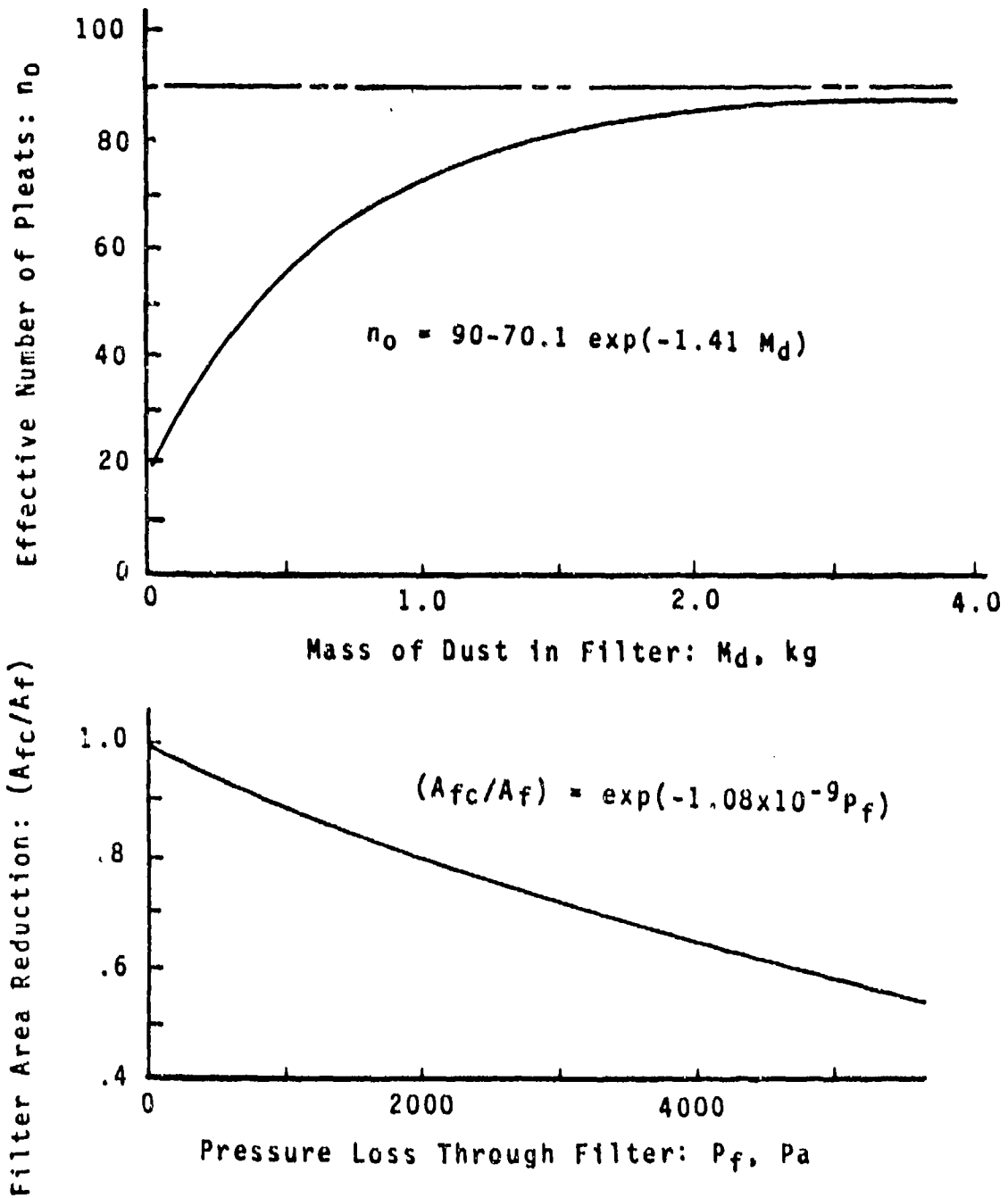


Figure 5.0-2 Area Reduction Functions

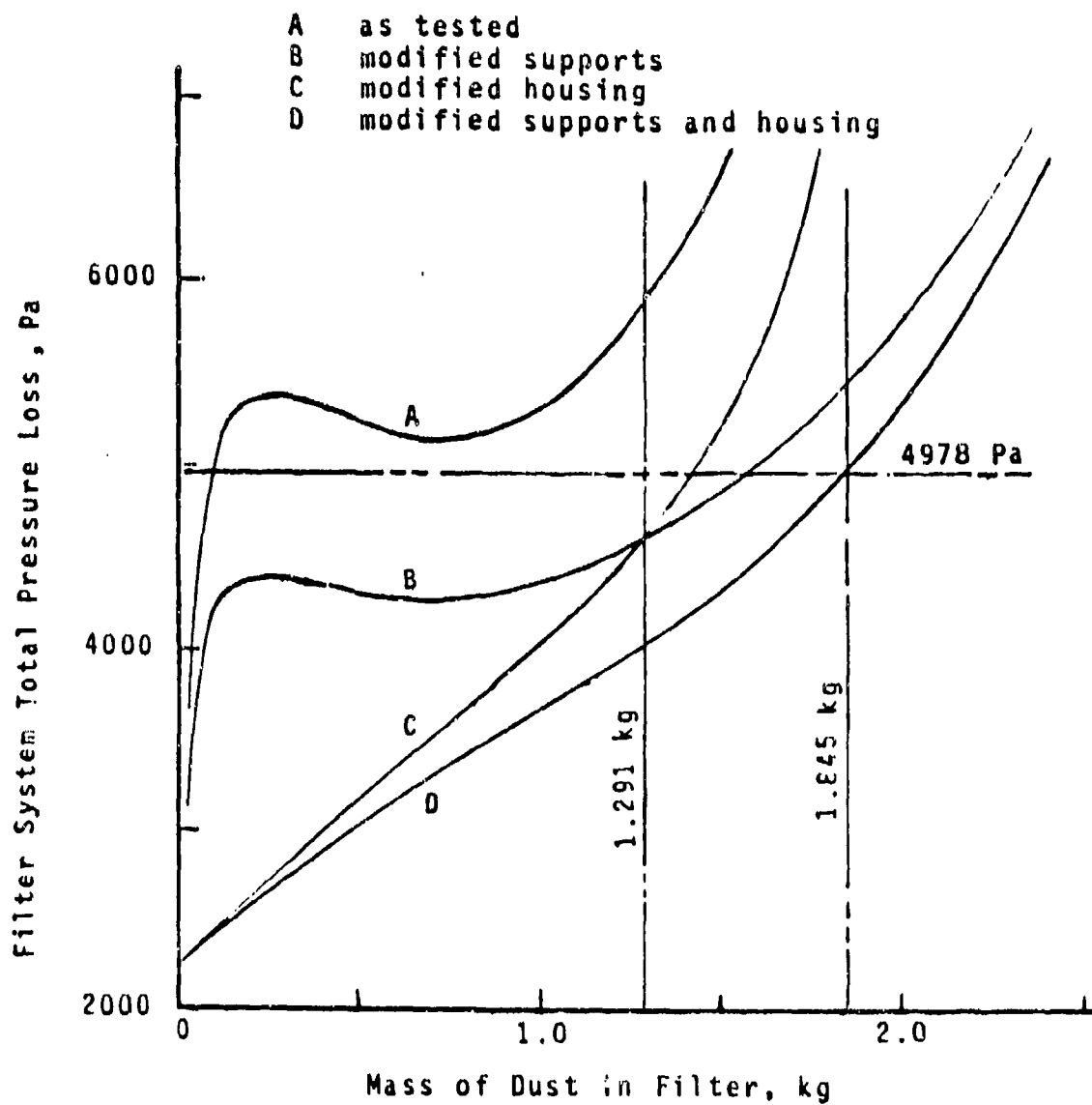


Figure 5.0-3 Dust Capacity Estimates

6.0 DISCUSSION

It is unfortunate that the test was terminated early and that more data was not taken. The limited amount of data greatly complicated the analysis. A thorough analysis was performed, however it required an extraordinary effort.

The air distribution to the filter by the filter housing is surprisingly un-even. This can be corrected by a proper system of baffling within the filter housing. Such baffling is amenable to analysis and can readily be developed. Such an effort is clearly outside the scope of the effort being reported.

A media support system can be used which will have negligible filter blockage. The corrugated spacers were used because of their mechanical simplicity and effectiveness.

It is quite obvious from these tests that the filtering performance characteristics of the metal mesh media are equal to the media commonly used in vehicle applications. The advantage of the metal mesh media lies in their extremely high strength and durability. This results in an extremely long life and permits cleaning with a shock wave.

Whether or not the indicated modifications should be made to this experimental filter depends on the use to which the government intends to put the filter. It can be used as is to demonstrate the durability and cleanability of a metal mesh filter. The filter can be installed in the 2½ ton truck and operated. Only the operating time between cleanings will be limited.

The metal mesh filter media data required for the shock wave cleaned filter development program have been gathered. The feasibility was never in doubt. The work being reported confirms the results reported in Reference 1 and 2.

7.0 COMMENTS

In test work a distinction must be made between acceptance testing and development testing. In the work being reported, acceptance testing procedures were used for the development testing of a filter element. This was a mistake and led to unnecessary complications of the associated analytic work. In acceptance testing, one measures a characteristic of a previously developed item to be sure that it meets a requirement established in its development program. Development testing is done in support of a development program to gain insights into the behavior of an item under development. A development test is really an experiment and this experiment should be carefully designed to assure that the test measures the phenomena under question. The accepted procedure for development testing is:

1. develop an analytic model of the phenomena under question,
2. design an experiment which measures the parameters of the analytic model,
3. perform the experiment,
4. compare the data obtained in the experiment with the analytic model and refine the model to reduce the differences,
5. design a new experiment which measures the parameters of the new analytic model,
6. perform the new experiment.

This cycle of analysis and test is repeated until one converges on the required understanding of the phenomena under question. This principle of development testing is thoroughly established and generally accepted. One deviates from it only at his peril. In the present case, little thought was given to the design of the experiment and no provision was made for a follow-on test program. This resulted in an inordinate amount of follow-on analytic work.

With the work presently being reported and that reported in References 1 and 2 we have obtained an understanding of the properties of metal mesh media that is more than adequate to develop a compact shock wave cleaning system for military vehicles. We must now proceed with the development of the shock wave cleaning system.

8.0 REFERENCES

1. Bos, William F., P.E., Donald H. Ostby and Lee Ann Ramthun, "Preliminary Evaluation of Ultra Fine Wire Mesh Filter Media for Application to Air Filters for Diesel and Turbine Powered Combat Vehicles," U.S. Army Tank-Automotive Command Research and Development Center Report 12891, January, 1984
2. Bos, William F., P.E., Donald H. Ostby and Lee Ann Ramthun, "Evaluation of Ultra Fine Metal Mesh Filter Media in Pleated Configuration for Application to Air Filters for Diesel and Turbine Powered Combat Vehicles," U.S. Army Tank and Automotive Command Research and Development Report 13203, March 1985
3. Ostby, Donald H., "Induction Air Filter for 2½ Ton Truck (Assembly)," Fil-Tech Systems Inc. dwg #DOD 84-12-1 dated 12-8-84

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