

TARDEC

---TECHNICAL REPORT---

THE NATION'S LABORATORY FOR ADVANCED AUTOMOTIVE TECHNOLOGY

No. 13752



WINNER OF THE 1995 PRESIDENTIAL AWARD FOR QUALITY

LAB TEST OF MIPS TURBODYNE II PRECLEANER
WITH SCAVENGE BLOWER MOTOR

JULY 1998

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By

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13. ABSTRACT (Maximum 200 words) An engine induction air precleaner system designed for the MIPS was lab tested at both TARDEC and SwRI to measure pressure drop, efficiency and particle size determination. The Turbodyne II Precleaner is a two-stage precleaner installed up-stream of turbocharged diesel engines. A self-cleaning rotating barrier filter is the second component of the Turbodyne II self-cleaning air filter (SCAF) system and is installed after the turbocharger. Two previous tests of the Turbodyne II SCAF were conducted: (1) Reference Appendix A, report page and abstract and (2) Reference Appendix B, report page and abstract. Test results showed in general: (1) Turbocharger degradation does not occur when exposed to precleaned air and (2) some minor difficulty occurred in achieving normal efficiency requirements and/or pressure drop limits across SCAF barrier filter for up to 200 hours. TARDEC and SwRI pressure drop lab tests were in agreement reaching a maximum of 11.2 to 11.4 inches of water at rated flow of 2600 cfm. Likewise efficiency testing at TARDEC and SwRI conducted on PTI coarse test dust was nearly in agreement with TARDEC obtaining an average overall efficiency of 98.15% compared to the slightly higher average overall efficiency of 98.624% obtained by SwRI. Turbodyne II precleaner particle size determination tests conducted by SwRI (See Appendix C, report) showed for three dust concentrations (zero visibility, half zero visibility and quarter zero visibility) separation efficiency at low concentration levels becomes more sensitive to airflow. For the three dust concentrations tested, test results showed the precleaner had an effective cut size ranging from about 3 to 6.5 microns depending on concentration and airflow rate. The cut size is the particle size where the probability of collection is 50%.				
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FOREWORD:

The testing activities described in this report were performed for the Propulsion Product Support Team of the Research Business Group. Funding was provided through the Propulsion Product Support Team. Funding was also provided through the Propulsion Product Support Team for the particle size determination testing done by SwRI. A surge contract was already in place with SwRI and a work directive was issued to them to conduct the particle size determination on the TD II pre-cleaner. A verbal agreement given by Satya Kodali, Team leader of the Crusader Team, to conduct the testing since a similar type Turbodyne II air cleaner system as designed for the MIPS would be used on the Crusader Program.

The Propulsion Product Support Team and the Mobility Test Operations Team worked together to conduct the TD II pre-cleaner testing. Program efforts and test findings were coordinated through Frank Margrif member of the Propulsion Product Support Team. Other personnel inside and outside the government played a part in the lab test efforts both at TAREC and SwRI to complete the project.

Set-up, Testing, Hardware and Final Report: (Government personnel)

-Mr. Larry Sierpien, Mobility Test Operations, instrumental in fabrication fixtures for test set-up and conducting lab tests.

-Mr. Mike McDuffee, Mobility Test Operations, assisted in conducting some of the lab tests. Also assisted in set-up/operations of computer data gathering equipment.

-Mr. Mike Richard, Mobility Test Operations, lead engineering technician in conducting lab test, and set-up of airflow controls and calculations to conduct tests. Verify and monitor test data to assure accuracy of test data.

-Mr. Julian Kozowyk, Team Leader, Mobility Test Operations, provide coordination and scheduling of his team members in conducting of lab tests.

-Ms. Mary Resop, Mobility Propulsion, TARDEC, prepared many tables and sections of final report.

Testing Support (non- governmental personnel):

-Mr. Martin B. Treuhaft, Manager Filtration and Fine Particle Technology, Engine and Vehicle research Division, SwRI, provided coordinated efforts with TARDEC technical and test personnel in conducting TD II pre-cleaner performance tests.

-Mr. Wayne Balla, Representative from EG & G Rotron, Rotron Inc., supplier of scavenging blower motor, provided technical performance data on scavenging blower motor and general information on Vane-axial Fans.

- Mr. Kenneth B. Zella, Program Manager, Pall Aeropower Corporation, supplier and manufacturer of TD II pre-cleaner, assisted TARDEC through providing performance data on TD II pre-cleaner and suggestions/concurrence of TARDEC test program. He also assisted in obtaining pertinent data and answers to technical questions regarding testing of TD II pre-cleaner and scavenging blower motor.

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ABBREVIATIONS/ACRONYMS

DEFINITION

ABBREV/ACRONYM

Medium Integrated Propulsion System	MIPS
Turbodyne II	TDII
Scavenge Blower Motor	SBM
Self-Cleaning Air Filter	SCAF
Society of Automotive Engineers	SAE
Southwest Research Institute	SwRI
U.S. Army Tank-automotive Research, Development & Engineering Center	TARDEC
Powered Technology Incorporated	PTI
Standard Cubic Feet Per Minute	SCFM/scfm
Cubic Feet Per Minute	CFM/cfm
Square Feet	FT ² /ft ²
Percent	%
Cubic Feet	FT ³ /ft ³
Square Inches	IN ² /in ²
Feet Per Minute	FT/MIN
Pounds Per Cubic Foot	LBS/ft ³
Inches of Water	H ₂ O
Times	X

1.0 SUMMARY

A Turbodyne (TD) II two-stage pre-cleaner designed for the MIPS power package was lab tested at both TARDEC and Southwest Research Institute (SwRI). TD II pre-cleaner performance characteristics including pressure drop and gravimetric efficiency were measured both at TARDEC and SwRI. In addition SwRI conducted particle size determination tests to measure the size of particles escaping the pre-cleaner and fractional efficiency tests for three dust concentration levels.

The TD II two-stage pre-cleaner is the first section of a Turbodyne II Self-Cleaning Air Filter (SCAF) system used for diesel engines. The TD II pre-cleaner is positioned ahead of the turbocharger and the rotating barrier filter or self-cleaning section is positioned downstream of the turbocharger.

The authors of this report had knowledge of two lab tests and one field test that had been conducted on two separate Turbodyne II Self-cleaning Air Filter Systems. The earlier lab test was conducted at TARDEC's Propulsion lab facilities from March to June 1987. A TD II SCAF system was designed for a Cummins VTA-903 engine rated at 500 horsepower. Dust was feed to the engine for 200 hours. General test results showed that the pre-cleaner gave adequate protection to the turbocharger compressor wheel. Some minor difficulties that occurred to the barrier filter caused by (in the manufacturer's opinion) a manufacturing problem in the sintering operation used to repair cracks in the pleat crown. The manufacturer believed that by adding additional annealing steps in the manufacturing cycle, cracking could be eliminated during the pleating operation. This phenomenon resulted in an increase in silicon entering the engine's oil system but dust particles were small in size, which reduced excessive engine wear. Also, the efficiency dropped from approximately 99.8 % in early part of testing to approximately 99.4 % after 80 or so hours and remained there. Efficiencies should have measured 99.95 % plus for most of the 200 hour test period.

A second test was conducted in August 1995 on a TD II SCAF System designed as a retrofit for M88A1 Recovery Vehicle using an AVDS 1790-2DR engine. The field test was terminated when self-cleaning components malfunctioned and later when the differential pressure increase rate exceeded the cleaning capability of the barrier system. Follow-on lab testing by the SCAF manufacturer was conducted in 1996 and testing was terminated when it became apparent the element differential pressure increase rate exceeded the cleaning capability. The specific cause of the reduced cleaning capability was under investigation.

Both of these tests (1987 and 1995/1996) are detailed in final reports. Appendix A and B should provide enough information to obtain a copy of one or both of these reports.

TARDEC lab tests on the TD II pre-cleaner used a scavenging blower motor (SBM) which was sized for the MIPS TD II SCAF System. TARDEC lab tests were conducted with SBM positioned in two locations. One location was termed, "close mount" since the

SBM was as close to the TD II pre-cleaner scavenging outlet duct as possible. The second location was termed, "30 inch mount" since the SBM was positioned 30 inches away from the TD II pre-cleaner scavenging outlet duct. The 30 inch mount location allowed restriction measurements to be made both before and after the SBM to obtain a total pressure drop for comparison with SBM manufacturer data. Figure 1 is a photo of the SBM positioned in the "30 inch mount location".

The manufacturer's SBM performance curve is shown in Figure 2. The curve shows the cyclic variations in airflow based on static pressure drop across the SBM. Figure 2 data shows SBM airflow decreases as static pressure increases until a preset static pressure is reached (9.6 inches of water). At this point a safety mechanism or relief valve kicks in to reduce airflow and static pressure drop. This downward cycle reduces airflow from 450 to 200 cfm and static pressure from 9.6 to 6.25 inches of water. At the lowest downward point of cycle (200 cfm and 6.25 inches of water) the cycle begins to increase upward again and then stops at zero airflow with a pressure drop of 12.5 inches of water.

TARDEC SBM performance tests provided some of the characteristics and curve shape of manufacturer's SBM performance, however TARDEC ran far fewer test points and under different test conditions than the manufacturer. For example, TARDEC tests could not measure a zero pressure drop across SBM. With a zero restriction on outlet side of SBM there was always a restriction ahead of the SBM for all airflow test points. TARDEC test data indicated with zero restriction on outlet side of SBM, the SBM airflow was nearly the same regardless of SBM mounting location. At the highest TD II pre-cleaner airflow test point, test data indicated, nearly a 3 % increase in SBM airflow when the SBM was mounted in the 30 inch mount location compared to the close mount location.

TARDEC test data showed that once the SBM maximum static pressure drop was reached, the SBM began to flow less air and correspondingly less pressure drop, which is similar to manufacturer's performance. Test data also showed the relief valve triggered at different SBM outlet restriction numbers for the two SBM mounting locations. For example, with the SBM mounted in the 30 inch location the relief valve did not trigger until 6 inches of water restriction was placed on the outlet side of SBM for 4 of the 5 airflow test points. Whereas, with the SBM installed in close mount position, the relief valve triggered when only 4.5 inches of water restriction was placed on the outlet side of SBM for 3 of the 5 airflow test points. This would indicate a higher restriction (even though not being measured) was occurring on up-stream side of SBM when it was located in the close mount position. However, as previously mentioned, mounting location and triggering of relief valve for tests with zero back pressure on outlet side of SBM produced similar SBM airflow results.

TARDEC testing measured restriction/pressure drop across the SBM and the TD II pre-cleaner. Maximum restriction occurred at a pre-cleaner primary/main airflow of 2650 cfm and measured 11.25 inches of water with SBM in close mount position and 10.4 inches of water with SBM in 30 inch mount location. In comparison, SwRI TD II pre-cleaner test



Figure 1: SBM Positioned in 30 Inch Mount Location



Measured: GBF
Project: SPR-3007

Test: A479-10

Model: MAXIAX
Type: S. 75-10

NOTES:
PERF. CK. 011417-500
STAINLESS STEEL PROP & CUST.
CONNECTOR NO FLAPPER VALVE
E/E COOLING BLADE DESIGN

ALB
3/18/94

Date: 3-18-94

Bench: N4-48-3

Flow: ☐ L ☐ R

RPM 11222

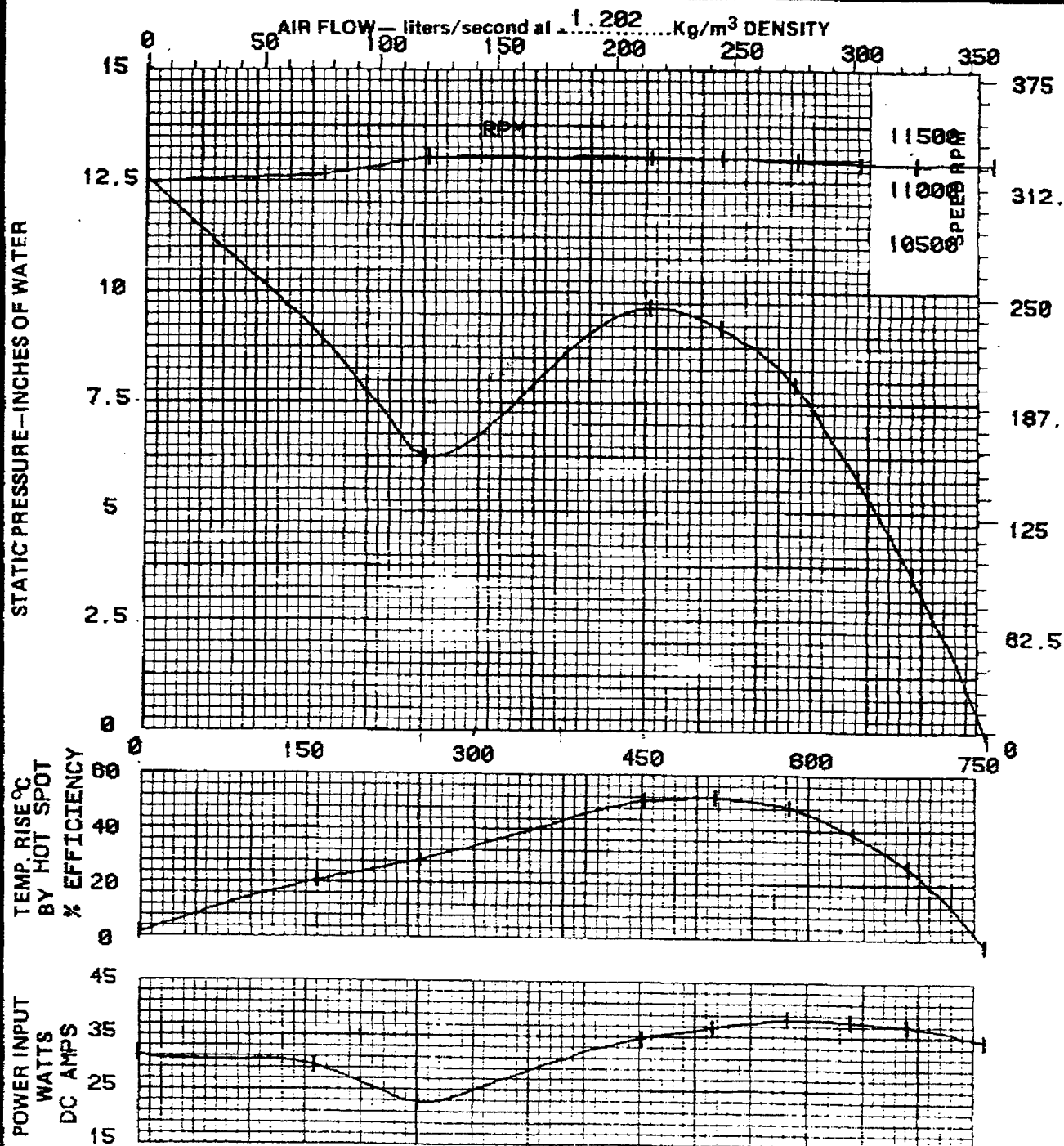
Line Amps 35.5

Locked Amps ---

Watts ---

MOTOR

Series 3195
Type ECDC
Volts 28.0
Wave DC
Phase 3
Hertz DC/
Mfd ---



Sheet 1 of 2

Figure 2: Manufacturer's Performance Curve of Scavenging Blower Motor (SBM)

data showed a restriction of 11.1 inches of water at 2600 scfm (corrected to an air density of .075 pounds per cubic foot).

TARDEC efficiency testing was conducted on both PTI fine and coarse test dust. Test results showed an average overall efficiency of 95.12 % on fine and 98.15 % on coarse. In comparison SwRI efficiency test on PTI coarse test dust showed an average overall efficiency of 98.624 %. The efficiency averaged about .5 % less during TARDEC tests than during SwRI tests. The largest difference occurred at the higher airflow test points of 2100 and 2600 cfm where TARDEC's efficiency was nearly 1 % lower than SwRI efficiency test data.

SwRI particle size determination test data showed in all but one case gravimetric efficiency test results exceeding efficiency predicted by particle size data by an average difference of 2.07 %. This was to be expected and is likely due to a combination of factors associated with the physics of measurement and dynamics of particle separation and transport mass. Gravimetric efficiency as a function of airflow rate for three specific upstream dust concentrations (zero visibility, half zero visibility and quarter zero visibility) showed a significant inverse dependency on concentration. At lower concentration levels, separation efficiency became more sensitive to airflow. At quarter zero dust visibility gravimetric efficiency decreases with airflow over the entire airflow range.

Fractional efficiency was calculated from the upstream and downstream particle size distributions for given particle size ranges as a function of airflow and inlet dust concentration. Tests were conducted at three dust concentrations of .025, 0.0125 and 0.000625 grams per cubic foot of air, respectively, independent of airflow over the primary airflow range of 600 to 2600 cfm. Test results showed the TD II pre-cleaner had an effective cut size ranging from about 3 to 6.5 microns, depending on concentration and airflow rate. This is the particle size where the probability of particle collection is 50 %. In all cases, collection efficiency was 90 % or higher at 10 microns and 99% or better at 15 microns.

2.0 INTRODUCTION

2.1 SUBJECT

This technical report describes the laboratory testing of a two stage Turbodyne (TD) II Pre-cleaner equipped with a scavenge blower motor (SBM). The TD II Pre-cleaner is part of the TD II Self Cleaning Air Filter (SCAF) System, which had been designed for a Medium Integrated Propulsion System (MIPS) Project. After completion of the MIPS program with AAI Corporation the TD II SCAF System became the property of TARDEC.

TARDEC had never run a performance test on a two stage pre-cleaner equipped with a SBM. It was decided with the support of the Vice President of the Research Business

Center and the Crusader Program Office that knowledge obtained from lab testing would benefit the Crusader's current TD II SCAF air cleaner development program. The Crusader's TD II SCAF System is similar to the MIPS TD II SCAF except it's designed for a slightly higher airflow.

TARDEC lab tests would provide a benchmark and database to determine the performance effects of the TD II Pre-cleaner with a functioning SBM. The SBM could also be positioned in different locations and be subject to different restrictions to determine its performance effects. The SBM was mounted in two locations which included a close mount set-up which was as close to the TD II Pre-cleaner scavenging outlet duct as possible and a 30 inch mount location which positioned the SBM 30 inches away from the TD II Pre-cleaner scavenging outlet duct. (See Figure 1)

Following TD II Pre-cleaner performance testing at TARDEC, the TD II Pre-cleaner was shipped to Southwest Research Institute (SwRI). Lab testing at SwRI would determine the fractional efficiency and micron size of dust particles exiting the clean side of pre-cleaner. Knowledge of the sizes of these dust particles could influence or be helpful in selecting turbocharger design criteria.

2.1.1 SCAVENGING BLOWER MOTOR DESCRIPTION AND PERFORMANCE

2.1.1.1 SCAVENGE BLOWER MOTOR DESCRIPTION

A general knowledge of the type of scavenging blower motor (SBM) used in the testing of the TD II Pre-cleaner was provided by the manufacturer, EG&G ROTRON. This information is shown in Appendix C. General remarks made by ROTRON on the axial-flow fan blower motor included the following: (1) The components present in an axial flow fan are a piece of duct constricted into a nozzle and a duct expanded into a diffuser, (2) The typical tip clearance of a vane axial fan is between 0.010 to 0.012 inches, (3) It is necessary for the diameter of the rotor to be less than that of the duct, (4) The rotor consists of a hub and aerofoil blades, the number of which varies from 4 to 8 with a limit between 2 and 50 blades, and (5) The axial flow fan also has upstream and downstream stationary guide vanes. Appendix C shows the major components of a vane axial flow fan, which include the propeller, stator, rotor, stationary guide vanes and diffuser.

2.1.1.2 SCAVENGE BLOWER MOTOR PERFORMANCE

The performance curve of the SBM was previously referenced in Figure 2. The SBM is a model MAXIAX and was flow bench tested under controlled conditions including an air density of 1.202 kilograms per cubic meter (.075 pounds per cubic foot). Figure 2 shows airflow on the bottom scale with a maximum CFM of nearly 750. The static pressure shown on vertical scale is in inches of water. The manufacturer indicated to the TARDEC air flow test team, the static pressure readings found in Figure 2 would be representative of the static pressures readings we would be measuring both before and after the SBM during some of our tests. Restriction readings both before and after SBM were measured

with the SBM mounted in the 30 inch mount location whereas with the SBM in the close mount location a restriction ahead of SBM could not be made. Figure 3 is a sketch of the positioning of the SBM to the TD II pre-cleaner. Figure 3 also shows other components and their relative positioning during TARDEC lab tests.

It is not possible to make a direct comparison between TARDEC'S test data and SBM manufacturers test data due to differences in test conditions/methods. A comparison of some of the major differences is as follows.

TARDEC Test Conditions	Manufacturer's Test Conditions
a. SBM coupled to TD II Pre-cleaner (See Figure 1)	a. SBM coupled to Bell mouth shroud not to pre-cleaner
b. SBM airflow calibrated to .073 pounds per cubic foot air density	b. SBM calibrated to a .075 pounds per cubic foot air density
c. SBM in close mount test set-up with TD II pre-cleaner causes a unknown restriction ahead of SBM	c. SBM Bell mouth inlet set-up provides a non-restrictive(zero) static pressure at inlet to SBM

2.1.2 TD II PRECLEANER DESCRIPTION, APPLICATION AND PERFORMANCE

2.1.2.1 TURBODYNE II PRECLEANER DESCRIPTION

The TD II pre-cleaner is part of a Turbodyne II Self-Cleaning Air Filter. The TD II pre-cleaner is a two-stage centrifuge design and is positioned up-stream of the turbocharger. A stainless steel barrier filter is located downstream of the turbo charger on diesel engine air intakes. After partially cleaned air has passed through the turbocharger it contacts the barrier filter. The barrier filter is self-cleaning by allowing a small portion of the turbocharger compressed air to back flush and clean a few pleats at a time as the barrier filter slowly rotates. The expelled dust is discharged through a blow back valve and dumped over board. The overall separation efficiency is 99.7 to 99.99 %.

The two-stage centrifuge inertial separator referred to as the Turbodyne II pre-cleaner is shown in Figure 4. The manufacturer claims a separation efficiency on SAE coarse test of 98 to 99 % and 92 to 93.5 % on SAE fine test dust. To obtain these efficiencies a 20 % scavenge flow rate is required.

2.1.2.2 TURBODYNE II PRECLEANER APPLICATION

The MIPS designed TD II pre-cleaner has a maximum airflow rating of 2640 CFM (3.3 pounds per second). The 2640 CFM is the expected maximum induction airflow of a model 8V92TA Detroit Diesel Engine with an 850 engine horsepower rating. The MIPS designed TD II air cleaner system has a total volume of 2.36 cubic feet. The volume of the TD II pre-cleaner is .92 cubic feet and the volume of the barrier filter is 1.44 cubic feet

8

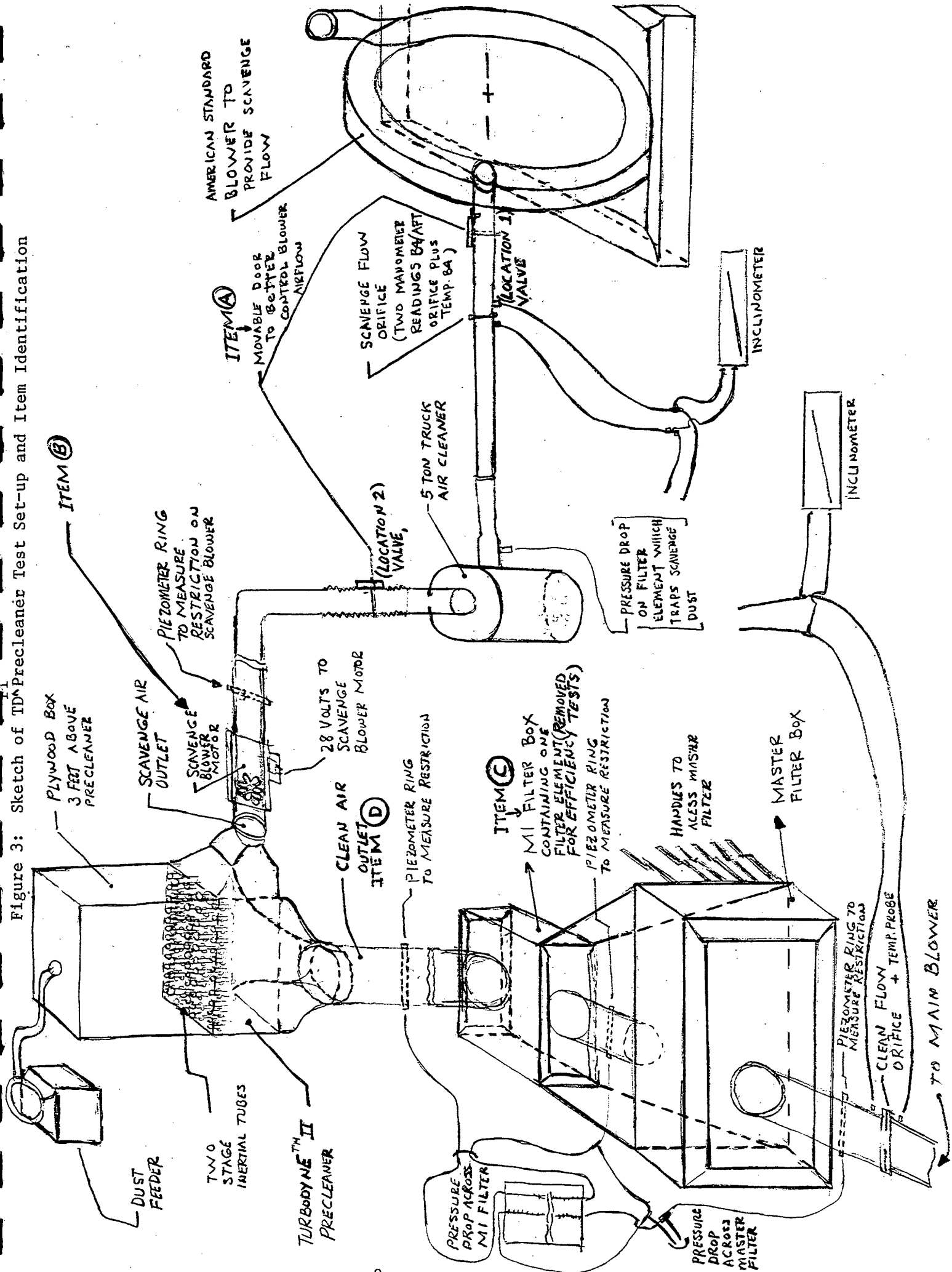
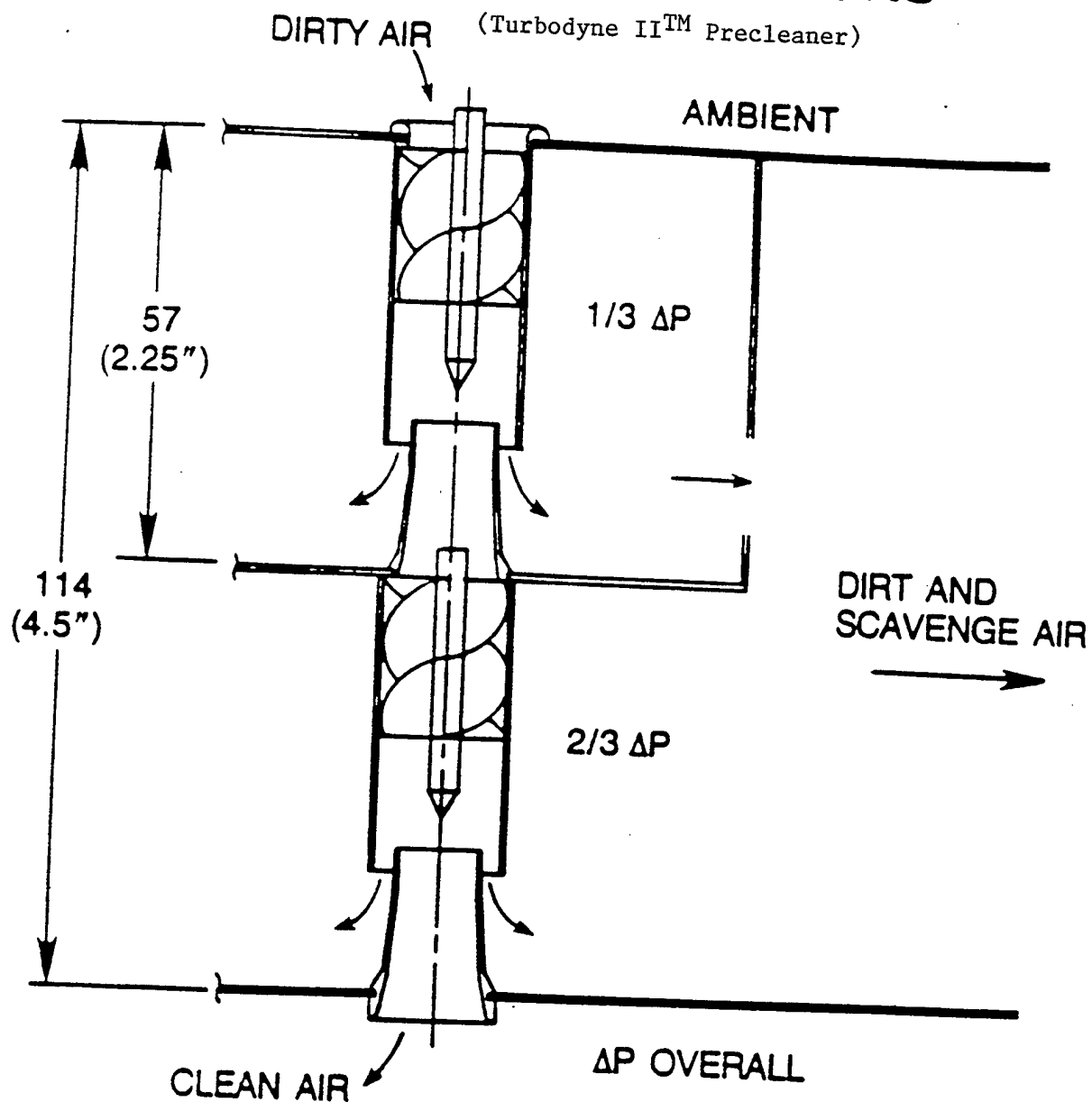


Figure 4

TWO STAGE CENTRISEP® INERTIAL SEPARATORS



SEPARATION EFFICIENCY—20% SCAVENGE TEST DUST

AC COARSE	98/99%
AC FINE	92/93.5%

 *solute Performance*

PALL

The dimensions and weight of the MIPS designed TD II pre-cleaner is shown in Figure 5. The pre-cleaner weighs about 17 pounds.

Figure 6 is a photo of the TD II pre-cleaner being held next to the turbocharger of the Model 8V92TA Detroit Diesel Engine. Figure 6 also shows the MIPS power package which include the major components of engine, transmission and TD II self-cleaning air filter. The self-cleaning air filter is shown as the cylindrical and silver colored component positioned on top of engine after the turbocharger.

The orientation of the TD II pre-cleaner shown in Figure 6 is also the orientation that was used during TARDEC lab tests. Test dust was fed at a height several feet above the inertial tubes, which are vertically mounted in Figure 6. Figure 7 shows an alternate orientation of the TD II pre-cleaner. The inertial tubes are horizontal in this position. Time did not permit tests to be conducted on the TD II pre-cleaner in this orientation.

2.1.2.3 PREVIOUS MIPS TD II AIR CLEANER SYSTEM PERFORMANCE

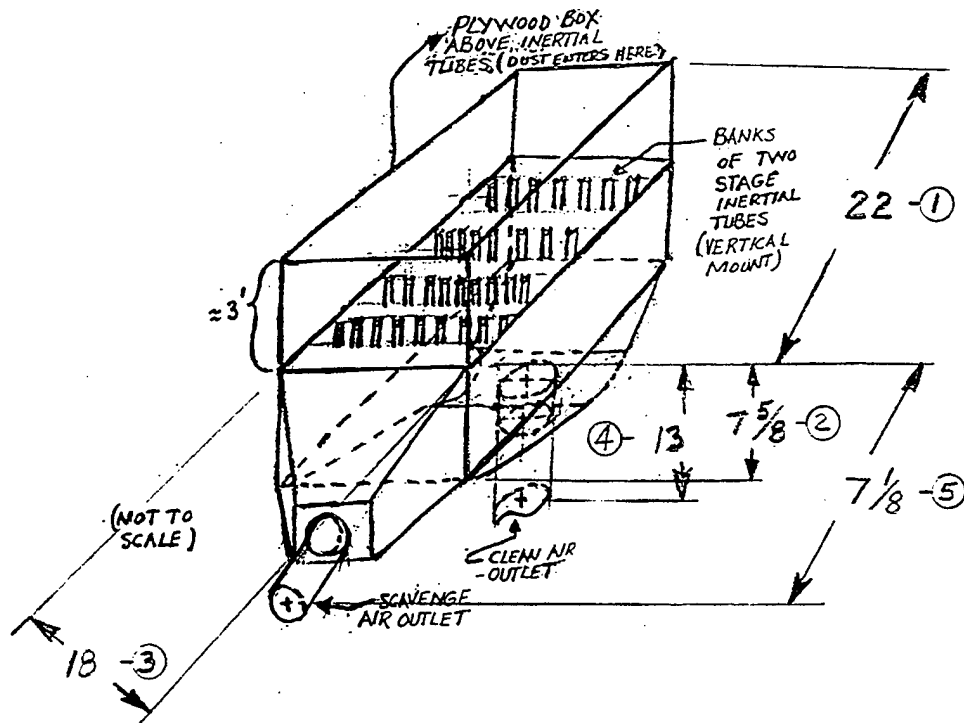
Components of the MIPS TD II air cleaner system were individually tested by the manufacturer or their representative prior to delivery to AAI Corporation for the installation of the self-cleaning air filter (SCAF). Appendix D is a lab test conducted by the manufacturer (Pall Aerospace Company) on the two stage TD II pre-cleaner. Test results show separation efficiency on SAE coarse test dust of 98.6 % and 98.73 % for two separate tests which exceeded the 98.0 % design goal. These tests also show a pressure drop of 9.6 inches of water at the 2640 cfm rated airflow test point. Tests were conducted at a fixed scavenging airflow rate of 520 cfm, which are about 20 % of the 2640 cfm rated airflow.

Appendix E is the lab tests conducted on the self-cleaning air filter for the MIPS power package. The SCAF was not tested with the TD II pre-cleaner attached and dust tests were conducted at a constant 60 % of rated airflow. Following these lab tests the SCAF was shipped to AAI Corporation for installation on the MIPS power package as shown in Figures 6 and 7.

2.2 PURPOSE/BACKGROUND

The reason for testing the MIPS two stage TD II pre-cleaner was to gain some knowledge in two-stage pre-cleaner performance. In addition, TARDEC lab data could be compared to the performance data obtained by TD II pre-cleaner manufacturer. Also, TARDEC could verify the manufacturer's desired TD II pre-cleaner efficiency of 98.0 % when tested on coarse test dust.

A secondary reason for TARDEC testing was to determine how positioning the scavenging blower motor (SBM) to the TD II pre-cleaner influences TD II pre-cleaner efficiency. By having the SBM installed at different locations, it was hoped that



DIMENSION 1 -	LENGTH =	22 INCHES
DIMENSION 2 -	HEIGHT =	7 5/8 INCHES
DIMENSION 3 -	WIDTH =	18 INCHES
DIMENSION 4 -	CLEAN OUTLET HEIGHT =	13 INCHES (FROM TOP PLANE)
DIMENSION 5 -	SCAVENGE OUTLET LENGTH =	7 1/8 INCHES (FROM FRONT EDGE OF TOP PLATE)

WEIGHT OF PRECLEANER = 16.95 POUNDS (7687 GRAMS)

Figure 5: Dimensions and Weight of Turbodyne II Precleaner

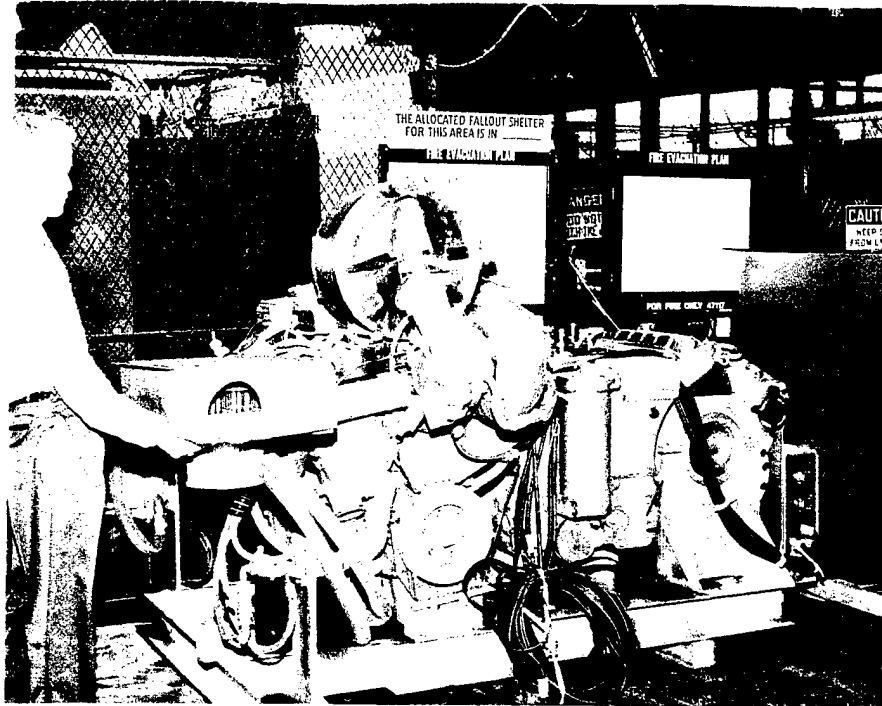


Figure 6: MIPS Power Package Configuration Showing Typical Location for Turbodyne II Precleaner

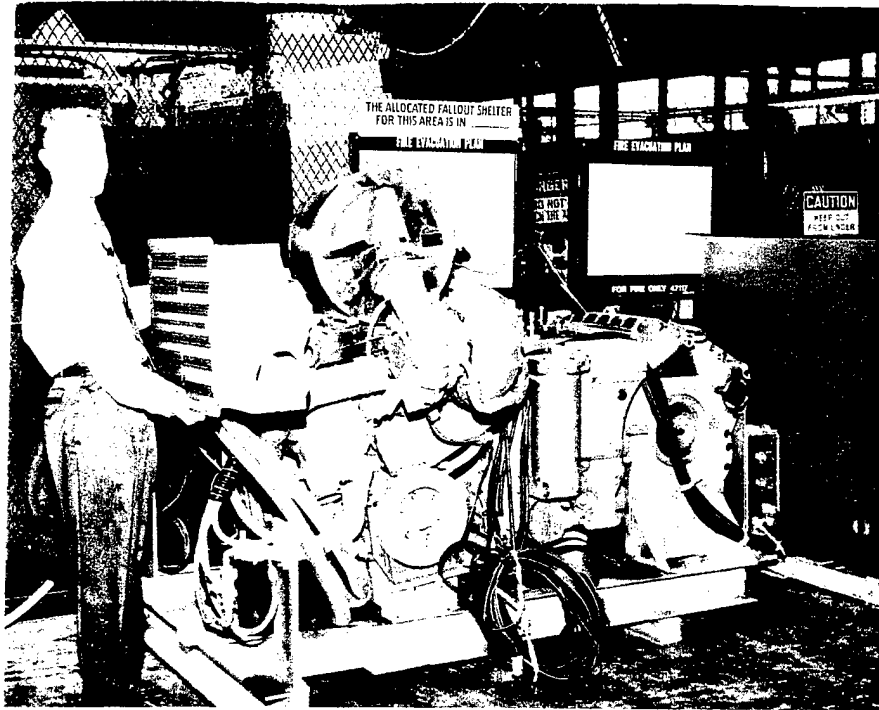


Figure 7: Alternate Location/Positioning of Turbodyne II Precleaner on MIPS Power Pack

measurable performance differences could be observed. The TARDEC airflow test team also wanted to measure scavenging airflow performance of the SBM and compare it to the SBM manufacturer's performance data.

The MIPS TD II SCAF system designed by Pall appears a similar design to the upcoming Crusader TD II SCAF. The Crusader TD II SCAF designed by Pall will be designed for a 1500 horsepower Perkins diesel engine with an airflow of around 3.75 pounds per second. Thus, it was hoped that knowledge gained from the TARDEC testing would be helpful in the Crusader SCAF design.

Another valuable part of this project was a separate work directive funded to Southwest Research Institute (SwRI) in San Antonio, Texas. Their project effort was to determine the size and concentration of dust particles for various dust feed rates, which escape through the TD II pre-cleaner. It was hoped this information would be valuable to the turbocharger and TD II pre-cleaner manufacturers.

3.0 TEST PLAN/TEST DESCRIPTION/TEST SET-UP

3.1 TEST PLAN/DESCRIPTION

Appendix F shows the TARDEC test plan written for the TD II pre-cleaner test. Page F-2 of Appendix F shows configuration 1, which was the orientation/positioning of the TD II, pre-cleaner during all TARDEC testing. This same positioning was used by SwRI during all their efficiency and particle size determination testing. SwRI lab testing was conducted at a constant 20 % scavenging airflow of the primary airflow. In contrast, TARDEC lab tests were conducted at scavenging airflow rates, which varied from 22 to 115 % of primary airflow.

Configuration 1 test orientation requires the airflow to pass through the inertial tubes in a vertical flow direction. The instrumentation locations used during TARDEC lab tests are detailed in paragraph A, sub-paragraph 1, page F-2 of Appendix F. However, a clearer picture showing the location of these instrumentation points is shown in Figure 3. Configuration 2 shown on Page F-3 of Appendix F was another orientation/positioning arrangement of the TD II pre-cleaner for scheduling testing, however time and funds prevented this from occurring.

The term's primary airflow, clean airflow and main airflow all mean the same and represent the airflow exiting the main duct of the TD II pre-cleaner. The main duct of TD II pre-cleaner is shown in Figure 3, Item D.

The airflow numbers recorded during TARDEC tests were corrected to an air density of .073 pounds per cubic foot. To correct TARDEC airflow numbers to an air density of .075 pounds per cubic foot (which is considered standard airflow and termed SCFM) the corrected airflow determined at an air density of .073 must be multiplied by the ratio of .073 divided by .075. This will always produce a lower airflow than is recorded on

TARDEC test data sheets. The TARDEC airflow numbers were not corrected to the standard air density of .075 pounds per cubic foot unless stated.

3.2 TEST PLAN CORRECTIONS

Special changes or cancellations to the test plan shown in Appendix F were made as needed. A list of changes or cancellations is as follows:

- A. Page F-3, Paragraph A, Sub-paragraph 2; Tests were not conducted at scavenging airflow rates of 20 and 25 % of primary airflow. Tests were conducted at scavenging airflow rates of 10 and 15 % of primary airflow under special tests. The SBM was tested at a scavenging flow rate of 22% which is fairly close to the 20 to 25 % scavenging flow rate range.
- B. Page F-6, Paragraph D, Sub-paragraph 3, Item c; There were no efficiency tests conducted at a high dust feed rate of 5 times 0 dust visibility.
- C. Page F-6, Paragraph D, Sub-paragraph 4; TD II pre-cleaner efficiency tests were never run with SBM removed. All special efficiency tests were run with SBM in close mount position or in 30 inch mount location. Also, in Sub-paragraph 4, item b, there were no efficiency tests conducted at high dust feed rate of 5 times 0 dust visibility.
- D. Page F-6, Paragraph D, Sub-paragraph 5 and 6; Efficiency tests with SBM installed in configuration 2 were never conducted.
- E. Page F-6, Paragraph E; These tests were never conducted.

3.3 TEST SET-UP AND EQUIPMENT CHANGES DURING LAB TESTS

During early on restriction tests on SBM (31 Jan 97 to 4 Feb 97) the test set-up used a damper valve located on outlet side of Bldg. 7 scavenging blower equipment. The location of this valve is shown in Figure 3 and is identified as location 1, item A. This test set-up was also used to conduct all efficiency tests and all SBM restriction tests where there was zero back pressure on the outlet side of SBM.

SBM restriction tests starting on 5 Feb 97 used a test set-up with only one valve but in a different location. The new location is identified as location 2, item A in Figure 3 and is just ahead of the 5-ton truck air cleaner housing. Figure 8 shows a photograph of the valve just ahead of the cylindrical 5-ton truck air cleaner. This test set-up was used for all remaining SBM restriction tests through 11 Feb 97 where the restriction on the SBM outlet was greater than zero. The TARDEC airflow test team indicated that the valve in location 2 allowed them to better control main TD II pre-cleaner and SBM airflow's when applying back pressure on SBM.

Figure 9 shows an overall view of the test set-up used for TD II pre-cleaner tests. A more detail view of the TD II pre-cleaner test set-up is shown in Figure 10. Figure 11 shows the

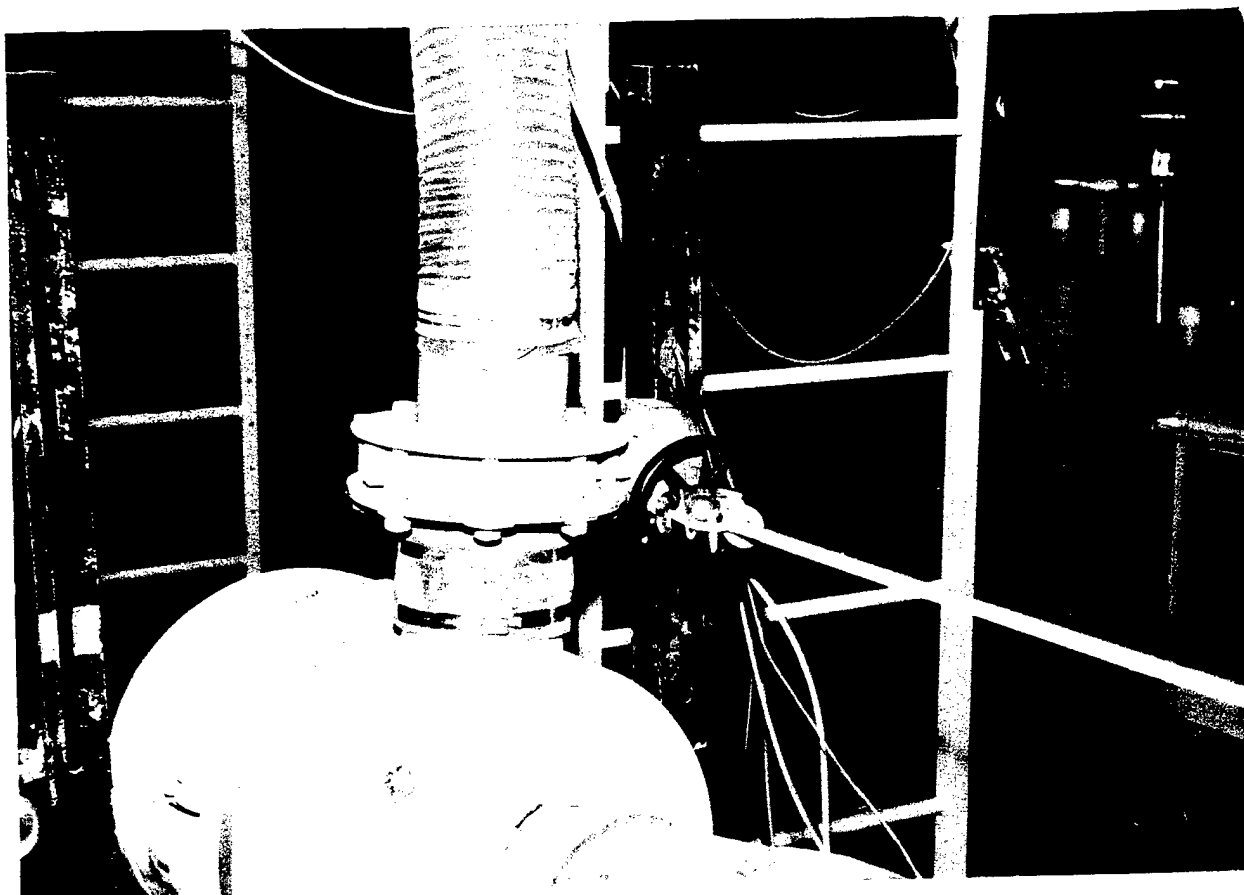


Figure 8: Adjustable Valve Located Before 5 Ton Truck Air Cleaner

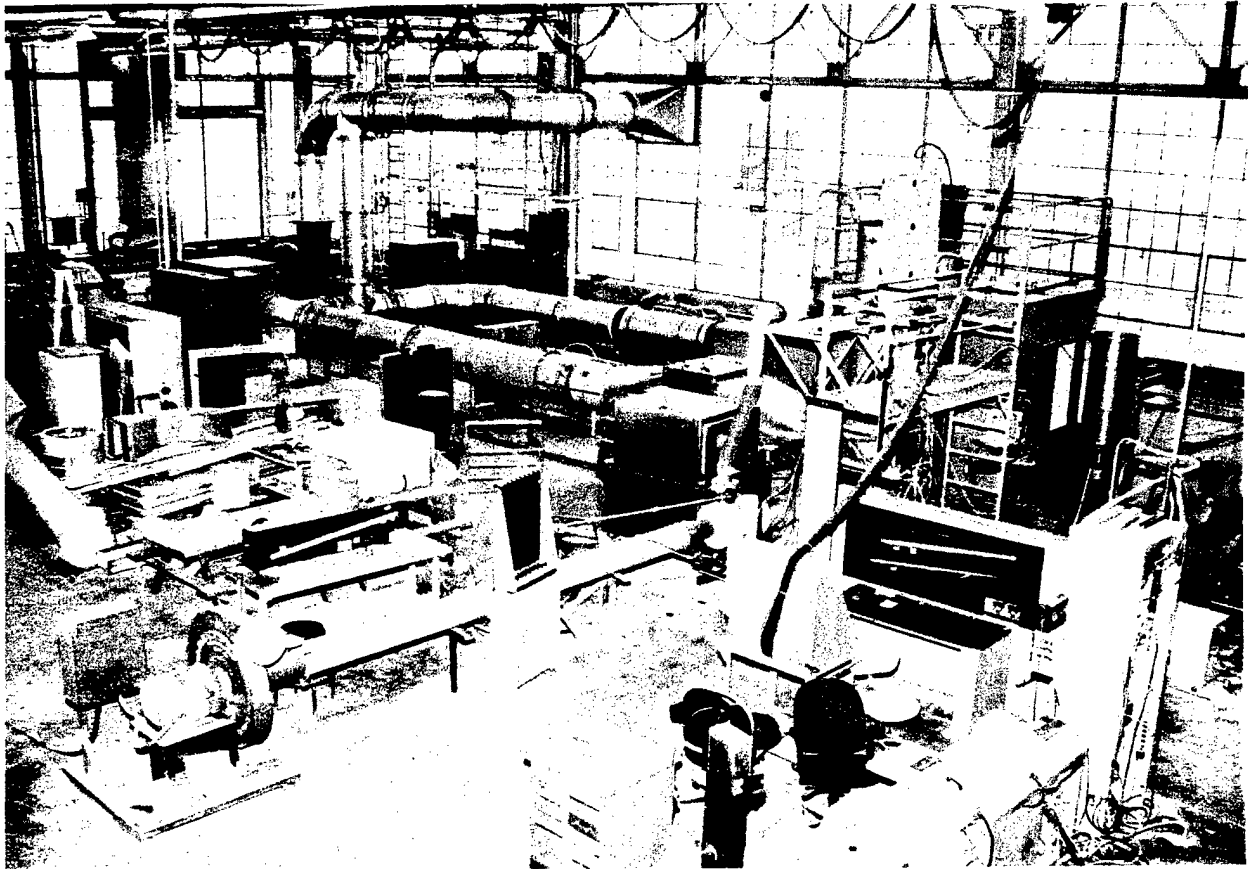


Figure 9: Overall View of TDII Precleaner Test Set-up



Figure 10: Closer/Detailed View of Turbodyne II Precleaner Test Set-up

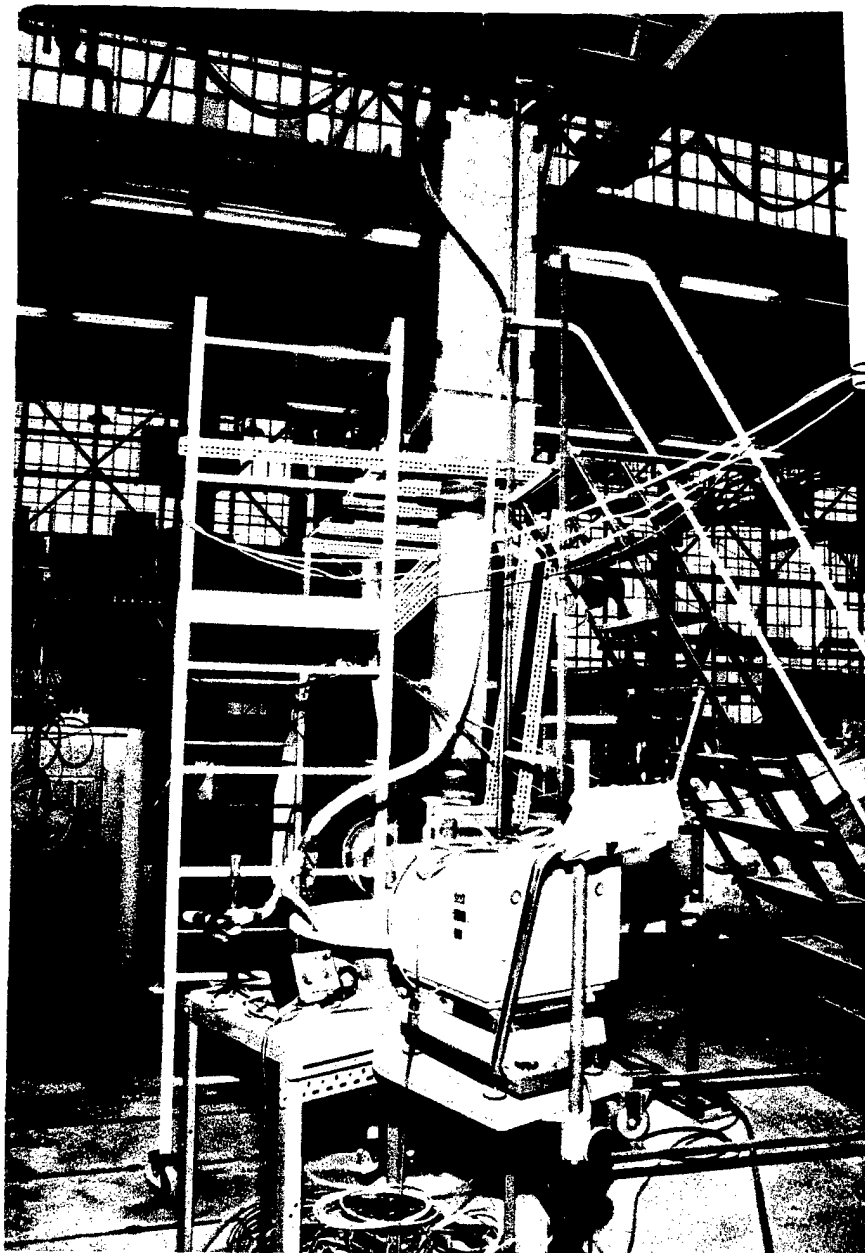


Figure 11: Dust Feeder Test Set-up For Turbodyne II Precleaner Lab Tests

dust feeder and it's location during TD II pre-cleaner efficiency tests. In Figure 11 observe the height of the rectangular plywood box above the TD II pre-cleaner, which is where, the dust entered. A close-up view of the TD II pre-cleaner and SBM is shown in previously presented Figure 1. Figure 1 shows the SBM positioned 30 inches away from the scavenging outlet duct of the TD II pre-cleaner. Also shown in Figure 1 is the restriction taps located both before and after the SBM. Figure 1 also shows the vertical main/primary airflow duct of the TD II pre-cleaner that flows to the master filter. The master filter used during efficiency testing is shown in Figure 12.

3.4 DUST FEED VARIATIONS BETWEEN TESTING COMMUNITIES

Appendix F details the amount of dust, which was feed to the TD II pre-cleaner during efficiency tests. The term "dust density" defined by TARDEC airflow test team is explained in Paragraph C, sub-paragraph 5 on page F-4 and paragraph D, sub-paragraph 3, item a, Page E-5 of Appendix F. During TARDEC efficiency tests, the test team chose to maintain a constant dust density of .0227 grams of dust feed per cubic foot of airflow. This meant that TARDEC tried to maintain a constant dust feed rate into the TD II pre-cleaner of .0227 grams of dust per cubic foot of airflow regardless of the scavenge flow rate. Other testing communities chose and or calculates slightly different "dust densities" or dust feed rates when they conduct their efficiencies tests.

Table 1 illustrates the variations in dust feed rates from three different test facilities for a 30 minute TD II pre-cleaner test. The results at 2650 cfm maximum primary airflow show TARDEC fed 10.5 % more dust than TD II pre-cleaner manufacturer and SwRI fed 21.5 % more dust than TD II pre-cleaner manufacturer and 10.0 % more dust than TARDEC for the 30 minute test period. At the low airflow test point (600 cfm), test results show TARDEC airflow lab fed 97.7 % more dust than TD II pre-cleaner manufacturer and SwRI fed 10.0 % more dust than TARDEC and 117.5 % more dust than TD II pre-cleaner manufacturer for the 30 minute test period. Table 1 shows SwRI normally feeds 10 % more dust than TARDEC's airflow lab because the dust density number that SwRI uses is .025 grams of dust per cubic foot of airflow instead of the .0227 grams of dust per cubic of airflow that TARDEC uses.

It is not the intention of this report to say who is right or wrong of if the amount of dust feed variation to a pre-cleaner make much difference. However dust feed variations to a barrier filter would make a difference and would have an impact on service life/dust capacity. It is believed that some standardization should be agreed upon and adopted by the SAE J 726 Test Code so that all testing facilities can test to the same dust feed rate whether it be a pre-cleaner, filter element or complete air cleaner assembly test.

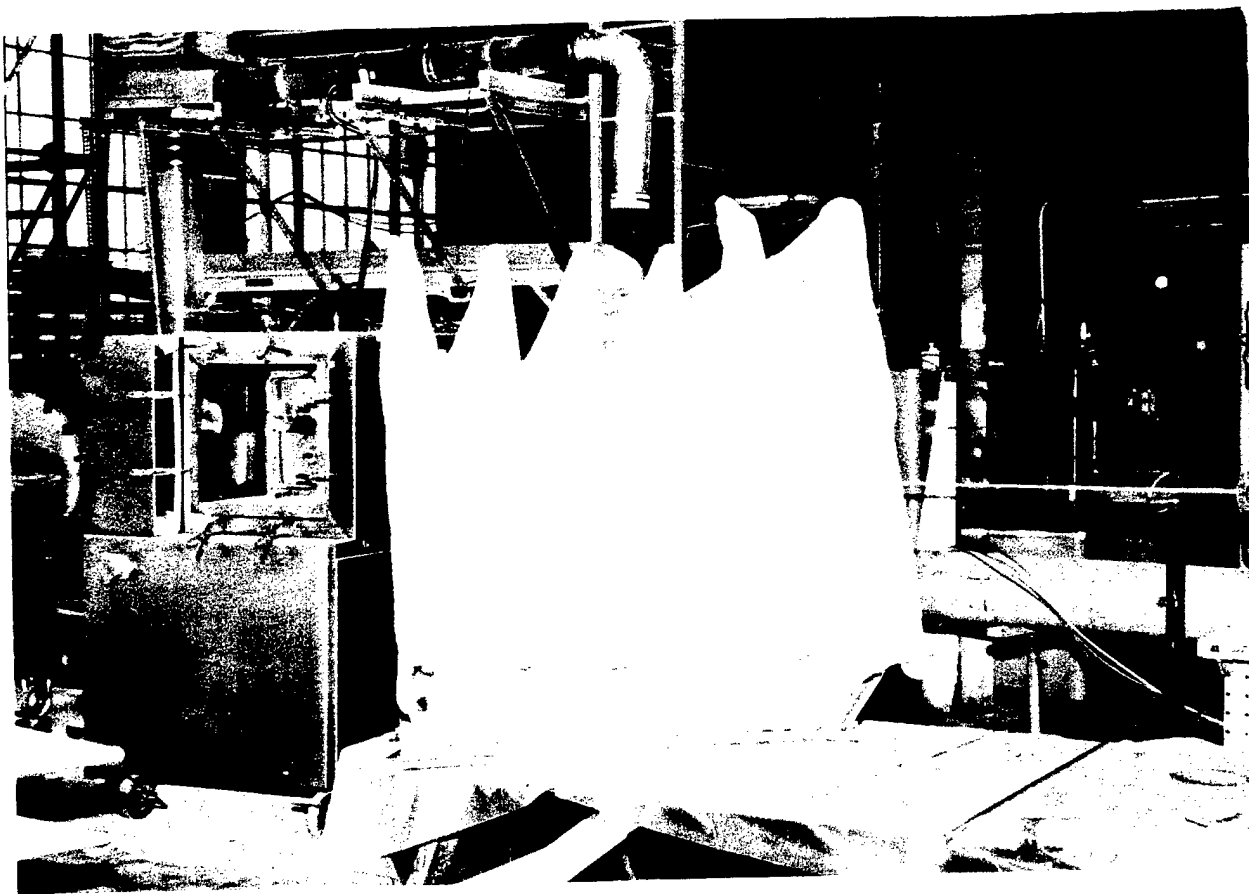


Figure 12: Master Filter Used for Turbodyne II Precleaner Efficiency Tests

TABLE 1
DUST FEED VARIATIONS AMONG TEST FACILITIES FOR TD II PRCLEANER TESTS

PRIMARY AIRFLOW (CFM)	PRECLEANER MFG. DUST FED TO PRECLEANER, (GRAMS)	TARDEC LAB TEST DUST FED TO PRECLEANER, (GRAMS)	SwRI LAB TEST DUST FED TO PRECLEANER, (GRAMS)	TARDEC DUST FEED INCREASE OVER MFG (%)	SwRI DUST FEED INCREASE OVER TARDEC (%)	SwRI DUST FEED INCREASE OVER MFG (%)
600	450	889.8	978.7	97.7	10.0	117.5
1100	825	1221.8	1344.0	48.1	10.0	62.9
1600	1200	1536.	1689.7	28.0	10.0	40.8
2100	1575	1851	2036.2	17.5	10.0	29.3
2650	1987.5	2196.1	2415.7	10.5	10.0	21.5

NOTES:

- (1) TARDEC dust feed based on actual scavenging flow rate obtained during SBM restriction tests; zero back pressure on SBM outlet, SBM scavenging flow rate data with SBM in close mount location, nearly same SBM flow with SBM in 30 inch mount location.
- (2) SwRI report found in appendix ran efficiency tests at constant 20% scavenging flow rate. Table presented above takes TARDEC's actual measured SBM airflow rates and adds to primary airflow. SwRI confirms that these combined airflows (primary and scavange) x .025 grams per cubic foot of air for 30 minutes is amount of dust they would normally feed.

4.0 RESULTS AND DISCUSSION

4.1 SCAVENGE BLOWER MOTOR AND TD II PRECLEANER RESTR. TESTS

4.1.1 SCAVENGE BLOWER MOTOR (SBM) RESTRICTION TESTS

4.1.1.1 SBM AIRFLOW RESTRICTION TESTS (30 INCH MOUNT LOCATION)

Table 2 shows the performance test data of the SBM when located 30 inches away from the TD II pre-cleaner scavenging outlet duct. The 30 inch mount location allowed restriction measurements to be made both before and after the SBM. Figure 1 shows the SBM in the 30 mount installation and the restriction tap locations. A recent visual examination of the Crusader Turbodyne II pre-cleaner assembly shows two scavenging blowers installed as an assembly of the Crusader TD II pre-cleaner. The Crusader design differs from the MIPS TD II pre-cleaner designs in that there are two SBM motors instead of one and the two SBM's are integrally designed into the pre-cleaner. The airflow for the Crusader TD II pre-cleaner is only slightly more than the MIPS TD II pre-cleaner (3.75 pounds per second airflow for the Crusader versus 3.3 pounds per second airflow for the MIPS).

Table 2 test data shows after 6 inches of water restriction is reached on outlet side of SBM for nominal/main airflow ranges of 600 to 2100 cfms, a safety mechanism kicks in which significantly lower SBM airflow output. At the highest airflow test point (2600 cfm) the safety mechanism of SBM kicks in before 6 inches of water restriction is reached. The restriction increments of 0, 1.5, 3.0, 4.5, and 6.0 inches of water are the restrictions recorded after the SBM and do not take into account restriction readings measured ahead of the SBM. The total restriction readings both before and after the SBM represent the total pressure drop or restriction across the SBM and can be compared to the manufacturer's SBM restriction numbers shown in Figure 2.

Tables 3 through 7 shows the performance test data of the SBM located in the 30 inch mount installation at individual restrictions of 0, 1.5, 3.0, 4.5 and 6.0 inches of water respectively after the SBM. Normally all restriction readings before/ahead of the SBM are vacuum readings and all restriction readings after/downstream of the SBM are pressure readings. Downstream of the SBM was a damper valve, which the airflow test teams, regulated to control the downstream SBM restriction. This valve was previously shown in Figure 3 and is identified as Item A. This valve was moved to location 2 whenever restrictions were placed on the SBM outlet duct.

Table 3 test data shows downstream SBM restriction readings were slightly negative, which was as close to a 0 restriction readings as could be obtained. Table 3 test data also shows the up-stream SBM restriction readings for each main airflow test point. The total pressure drop across the SBM is the addition of the restrictions before and after the SBM.

SBM AIRFLOWS AT VARIOUS RESTRICTIONS ("30" INCH MOUNT)

NOMINAL MAIN AIRFLOW (CFM)	SBM, CFM @ "0" INCH H ₂ O RESTR	SBM, CFM @ "1.5" INCH H ₂ O RESTR	SBM, CFM @ "3.0" INCH H ₂ O RESTR	SBM, CFM @ "4.5" INCH H ₂ O RESTR	SBM, CFM @ "6.0" INCH H ₂ O RESTR	SBM, CFM @ "7" INCH H ₂ O RESTR	SBM, CFM @ "7" INCH H ₂ O RESTR
600	707@ Avg 605 cfm main airflow	686@ Avg 608 cfm main airflow (1.1 inch H ₂ O Restr)	622@ Avg 609 cfm main airflow	581@ Avg 609 cfm main airflow (4.2 inch H ₂ O Restr)	474@ Avg 609 cfm main airflow (5.9 inch H ₂ O Restr)	292@ Avg 603.5 cfm main airflow (4.1 inch H ₂ O Restr)	76@ Avg 610 cfm main airflow (5.0 inch H ₂ O Restr)
1100	696 @ Avg 1106 cfm main airflow	642 @ Avg 1108 cfm main airflow (2.0 inch H ₂ O Restr)	567 @ Avg 1103 cfm main airflow (4.1 inch H ₂ O Restr)	466@ Avg 1103 cfm main airflow (5.6 inch H ₂ O Restr)	402 @ Avg 1107 cfm main airflow (4.5 inch H ₂ O Restr)	214 @ Avg 1109 cfm main airflow (3.7 inch H ₂ O Restr)	79 @ Avg 1107 cfm main airflow (4.5 inch H ₂ O Restr)
1600	641 @ Avg 1624 cfm main airflow	608 @ Avg 1623 cfm main airflow	573 @ Avg 1630 cfm main airflow	495 @ Avg 1612 cfm main airflow	327 @ Avg 1628 cfm main airflow (4.5 inch H ₂ O Restr)		
2100	629 @ Avg 2108 cfm main airflow	598 @ Avg 2108 cfm main airflow	592 @ Avg 2099 cfm main airflow (2.0 inch H ₂ O Restr)	532 @ Avg 2114 cfm main airflow (4.0 inch H ₂ O Restr)	482 @ Avg 2113 cfm main airflow	301 @ Avg 2117 cfm main airflow (3.7 inch H ₂ O Restr)	44 @ Avg 2114 cfm main airflow (5.63 inch H ₂ O Restr)
2650	633 @ Avg 2659 cfm main airflow (-1 inch H ₂ O Restr)	602 @ Avg 2654 cfm main airflow (1.0 inch H ₂ O Restr)	560 @ Avg 2657 cfm main airflow	492 @ Avg 2657 cfm main airflow	362 @ Avg 2661 cfm main airflow (3.51 inch H ₂ O Restr)	251 @ Avg 2652 cfm main airflow (2.51 inch H ₂ O Restr)	44 @ Avg 2653 cfm main airflow (3.94 inch H ₂ O Restr)

- NOTES: 1. SBM airflows measured at predetermined restrictions increments of 1.5 inches of H₂O, up to 6 inches.
2. Where an exact restriction increment of 0, 1.5, 3.0, 4.5, and 6.0 inches of H₂O was not obtained the obtained restriction recorded in parenthesis after the SBM airflow and average main airflow.
3. SBM airflows recorded to the right of (→) indicate where the SBM safety mechanism kicked-in which lowered airflows.
4. The "?" in columns to right of (→) indicates the various restrictions obtained for the five main airflows following SBM safety mechanism kick-in. Restrictions measured are recorded in parenthesis after SBM and main airflows.
5. Actual main airflow cfm's differs from nominal airflows due to averaging of several test runs.
6. Location of restriction readings obtained B4/upstream and Aft /downstream of SBM as shown by arrows designated A (upstream) and B (downstream) in Figure 1
7. Restriction readings obtained B4/upstream of SBM in 30 inch installation are recorded in Tables 2 through 7.
8. All airflows measured to an air density of .073 lbs/ft³.

**SBM & PRECLEANER AIRFLOW RESTRICTIONS FOR
SBM 30 INCH MOUNT INSTALLATION
(NOMINAL "0" INCH H₂O RESTR AFTER SBM)**

NOMINAL MAIN AIRFLOW CFM	UPSTREAM SBM RESTR (INCHES OF H ₂ O)	DOWNSTREAM SBM RESTR (INCHES OF H ₂ O)	TOTAL PRESSURE DROP (Δ P) ACROSS SBM (INCHES OF H ₂ O)	PRECLEANER PRESSURE DROP (Δ P) (INCHES OF H ₂ O)
600 (Actual main airflow average 605 cfm)	3.64	-.04	3.60	1.8
1100 (Actual main airflow average 1106 cfm)	4.09	-.02	4.07	2.4
1600 (Actual main airflow average 1624 cfm)	3.75	-.02	3.73	4.7
2100 (Actual main airflow average 2108 cfm)	4.18	-.03	4.21	7.3
2650 (Actual main airflow average 2659 cfm)	5.87	-.03	5.84	10.4

NOTES: Air flows calculated to a density of 0.073 LB per cu ft.
2650 cfm airflow average of 3 test runs

Table 3

These numbers are recorded in Column 4 of Table 3. Column 5 of Table 3 shows the TD II pre-cleaner pressure drop. Airflow's were measured at an air density of .073 pounds per cubic foot, however as previously discussed in Paragraph 3.1 TEST PLAN/DESCRIPTION airflow's can be corrected to an air density of .075 pounds per cubic foot.

Table 4 shows test data measured at a nominal 1.5 inches of water restriction after the SBM. The total pressure drop across the SBM is measured in inches of water and is shown in Column 4. The highest measured pressure drop was 6.32 inches of water and it occurred at the nominal/main airflow of 2650 cfm. TD II pre-cleaner pressure drop is shown in Column 5 of Table 4. TD II pre-cleaner pressure drops in Table 4 are nearly the same as shown in Table 3.

Table 5 shows test data measured at a nominal 3.0 inches of water restriction after the SBM. The total pressure drop across the SBM (column 4) reached a maximum value of 7.92 inches of water at the nominal or main airflow of 2650 cfm.

Table 6 shows test data measured at a nominal 4.5 inches of water restriction after the SBM. The total pressure drop across the SBM (column 4) reached a maximum value of approximately 9.0 inches of water at the nominal or main airflow of 2650 cfm.

Table 7 shows test data measured at a nominal 6.0 inches of water restriction after the SBM. The total pressure drop across the SBM (column 4) reached a maximum value of 9.1 inches of water at nominal airflow's of 1600 and 2100 cfm. When attempting to run at 6.0 inches of water restriction after the SBM at the 2650 cfm nominal airflow test point, the SBM built in relief mechanism/safety feature kicked in which lowered the SBM airflow. In other words, the total pressure drop across the SBM must have exceeded the manufacturer's limit of 9.6 inches of water (reference Figure 2) which caused the flow to drop. Table 7 test data in column 5 shows lower TD II pre-cleaner restrictions throughout the airflow test range than was measured in earlier tests at lower restrictions on outlet side of SBM. There is no explanation for this occurrence and it remains a mystery.

Table 8 (sheets 1, 2 and 3) shows the test data measured at each nominal/primary airflow (600, 1100, 1600, 2100 and 2650 cfm) after the SBM built in safety mechanism kicks in. The SBM was installed in the 30 inch mount installation, which allowed the restriction to be measured both before and after the SBM. Only one data point was taken at the nominal main airflow of 1600 cfm. Five test points indicated by asterisks recorded positive/pressure restriction readings when they should have been negative/vacuum readings. It is believed that the damper valve positioned downstream of the SBM caused an airflow reversal on inlet side of the SBM when the valve was closed or nearly closed.

Figure 13 is a graph showing how SBM restriction and scavenge airflow vary with TD II pre-cleaner airflow. The test data was plotted with SBM located in 30 inch mount location. Test results show the SBM restriction increases as the cfm flow range of TD II pre-cleaner increases except for the 1100 cfm (1077 cfm actual) TD II pre-cleaner airflow

**SBM & PRECLEANER AIRFLOW RESTRICTIONS FOR
SBM 30 INCH MOUNT INSTALLATION
(NOMINAL "1.5" INCH H₂O Restr After SBM, EXCEPT WHERE NOTED)**

NOMINAL MAIN AIRFLOW CFM	UPSTREAM SBM RESTR (INCHES OF H ₂ O)	DOWNSTREAM SBM RESTR (INCHES OF H ₂ O)	TOTAL PRESSURE DROP (Δ P) ACROSS SBM (INCHES OF H ₂ O)	PRECLEANER PRESSURE DROP (Δ P) (INCHES OF H ₂ O)
600 (Actual main airflow average 608 cfm)	3.42	1.1 (vs. intended 1.5 inches)	4.52	1.0
1100 (Actual main airflow average 1108 cfm)	3.67	2.0 (vs. intended 1.5 inches)	5.67	2.4
1600 (Actual main airflow average 1624 cfm)	3.50	1.5	5.00	4.6
2100 (Actual main airflow average 2108 cfm)	4.04	1.54	5.58	7.2
2650 (Actual main airflow average 2659 cfm)	5.29	1.03 (vs. intended 1.5 inches)	6.32	8.2

NOTES: Air flows calculated to a density of 0.073 LB per cu ft.

Table 4

SBM & PRECLEANER AIRFLOW RESTRICTIONS FOR
SBM 30 INCH MOUNT INSTALLATION
(NOMINAL "3.0" INCH H₂O Restr After SBM, EXCEPT WHERE NOTED)

NOMINAL MAIN AIRFLOW CFM	UPSTREAM SBM RESTR (INCHES OF H ₂ O)	DOWNSTREAM SBM RESTR (INCHES OF H ₂ O)	TOTAL PRESSURE DROP (Δ P) ACROSS SBM (INCHES OF H ₂ O)	PRECLEANER PRESSURE DROP (Δ P) (INCHES OF H ₂ O)
600 (Actual main airflow average 609 cfm)	3.01	2.96	5.97	1.0
1100 (Actual main airflow average 1108 cfm)	3.67	2.00 (vs. intended 3.0 inches)	5.67	2.4
1600 (Actual main airflow average 1630.5 cfm)	3.27	2.98	6.25	4.6
2100 (Actual main airflow average 2099 cfm)	4.73	1.99 (vs. intended 3.0 inches)	6.72	6.85
2650 (Actual main airflow average 2657 cfm)	4.89	3.03	7.92	8.2

NOTES: Air flows calculated to a density of 0.073 LB per cu ft.

SBM & PRECLEANER AIRFLOW RESTRICTIONS FOR
SBM 30 INCH MOUNT INSTALLATION
(NOMINAL "4.5" INCH H₂O RESTR AFTER SBM, EXCEPT WHERE NOTED)

NOMINAL MAIN AIRFLOW CFM	UPSTREAM SBM RESTR (INCHES OF H ₂ O)	DOWNSTREAM SBM RESTR (INCHES OF H ₂ O)	TOTAL PRESSURE DROP (Δ P) ACROSS SBM (INCHES OF H ₂ O)	PRECLEANER PRESSURE DROP (Δ P) (INCHES OF H ₂ O)
600 (Actual main airflow average 609 cfm)	2.62	4.24 (vs. intended 4.5 inches)	6.86	.9
1100 (Actual main airflow average 1103 cfm)	3.10	4.10 (vs. intended 4.5 inches)	7.20	2.3
1600 (Actual main airflow average 1612 cfm)	3.60	4.51	8.11	4.2
2100 (Actual main airflow average 2114 cfm)	4.29	3.99 (vs. intended 4.5 inches)	8.28	6.8
2650 (Actual main airflow average 2657 cfm)	4.42	4.54	8.96	8.0

NOTES: Air flows calculated to a density of 0.073 LB per cu ft.

Table 6

SBM & PRECLEANER AIRFLOW RESTRICTIONS FOR
SBM 30 INCH MOUNT INSTALLATION
(NOMINAL "6.0" INCH H₂O RESTR AFTER SBM, EXCEPT WHERE NOTED)

NOMINAL MAIN AIRFLOW CFM	UPSTREAM SBM RESTR (INCHES OF H ₂ O)	DOWNSTREAM SBM RESTR (INCHES OF H ₂ O)	TOTAL PRESSURE DROP (Δ P) ACROSS SBM (INCHES OF H ₂ O)	PRECLEANER PRESSURE DROP (Δ P) (INCHES OF H ₂ O)
600 (Actual main airflow average 609 cfm)	1.83	5.92	7.75	.9
1100 (Actual main airflow average 1103 cfm)	2.30	5.60 (vs. intended 6.0 inches)	7.89	2.1
1600 (Actual main airflow average 1612 cfm)	3.145	6.0	9.145	4.2
2100 (Actual main airflow average 2113 cfm)	3.11	6.01	9.12	4.6

Could not obtain 6.0 inch of H₂O restriction after SBM, since SBM built in safety mechanism kicked in, reducing SBM airflow and airflow restrictions B4 and Aft of SBM.

NOTE: Airflows calculated to a density of 0.073 LB per cu ft.

Table 7

SBM & PRECLEANER AIRFLOW RESTRICTIONS FOR
SBM 30 INCH MOUNT INSTALLATION
(AFTER SBM BUILT-IN SAFETY MECHANISM KICKS-IN)

NOMINAL MAIN AIRFLOW CFM	UPSTREAM SBM RESTR (INCHES OF H ₂ O)	DOWNSTREAM SBM RESTR (INCHES OF H ₂ O)	TOTAL PRESSURE DROP (Δ P) ACROSS SBM (INCHES OF H ₂ O)	PRECLEANER PRESSURE DROP (Δ P) (INCHES OF H ₂ O)
600 (Actual main airflow average 603.5 cfm)	.90	4.09	4.99	.70
600 (Actual main airflow average 606 cfm)	1.94	5.82	7.76	.85
600 (Actual main airflow average 610 cfm)	*+1.35	4.98	3.63	.55
600 (Actual main airflow average 614 cfm)	*+1.68	5.92	4.23	.54
1100 (Actual main airflow average 1107cfm)	1.97	4.60	6.53	2.1
1100 (Actual main airflow average 1109 cfm)	.27	3.66	4.57	1.8
1100 (Actual main airflow average 1107 cfm)	*+.71	4.51	3.79	1.7

Table 8

SBM AND PRECLEANER AIRFLOW RESTRICTIONS FOR
SBM 30 INCH MOUNT INSTALLATION
(AFTER SBM BUILT-IN SAFETY MECHANISM KICKS-IN)

NOMINAL MAIN AIRFLOW CFM	UPSTREAM SBM RESTR (INCHES OF H ₂ O)	DOWNSTREAM SBM RESTR (INCHES OF H ₂ O)	TOTAL PRESSURE DROP (Δ P) ACROSS SBM (INCHES OF H ₂ O)	PRECLEANER PRESSURE DROP (Δ P) (INCHES OF H ₂ O)
1600 (Actual main airflow average 1628 cfm)	2.18	4.51	6.69	4.0
2100 (Actual main airflow average 2117 cfm)	2.05	3.7	5.75	4.3
2100 (Actual main airflow average 2118 cfm)	1.16	3.98	5.14	4.1
2100 (Actual main airflow average 2114 cfm)	*+.72	5.63	4.90	4.0
2100 (Actual main airflow average 2122 cfm)	*+1.33	7.43	6.11	3.9
2650 (Actual main airflow average 2661 cfm)	3.60	3.51	7.11	7.75
2650 (Actual main airflow average 2652 cfm)	3.11	2.51	5.62	7.6

Table 8

SBM PRECLEANER AIRFLOW RESTRICTIONS FOR
SBM 30 INCH MOUNT INSTALLATION
(AFTER SBM BUILT-IN SAFETY MECHANISM KICKS-IN)

NOMINAL MAIN AIRFLOW CFM	UPSTREAM SBM RESTR (INCHES OF H ₂ O)	DOWNSTREAM SBM RESTR (INCHES OF H ₂ O)	TOTAL PRESSURE DROP (Δ P) ACROSS SBM (INCHES OF H ₂ O)	PRECLEANER PRESSURE DROP (Δ P) (INCHES OF H ₂ O)
2650 (Actual main airflow average 2662 cfm)	2.04	3.04	5.08	7.4
2650 (Actual main airflow average 2653 cfm)	.63	3.94	4.56	7.3
2650 (Actual main airflow average 2657 cfm)	.03	5.35	5.38	7.3

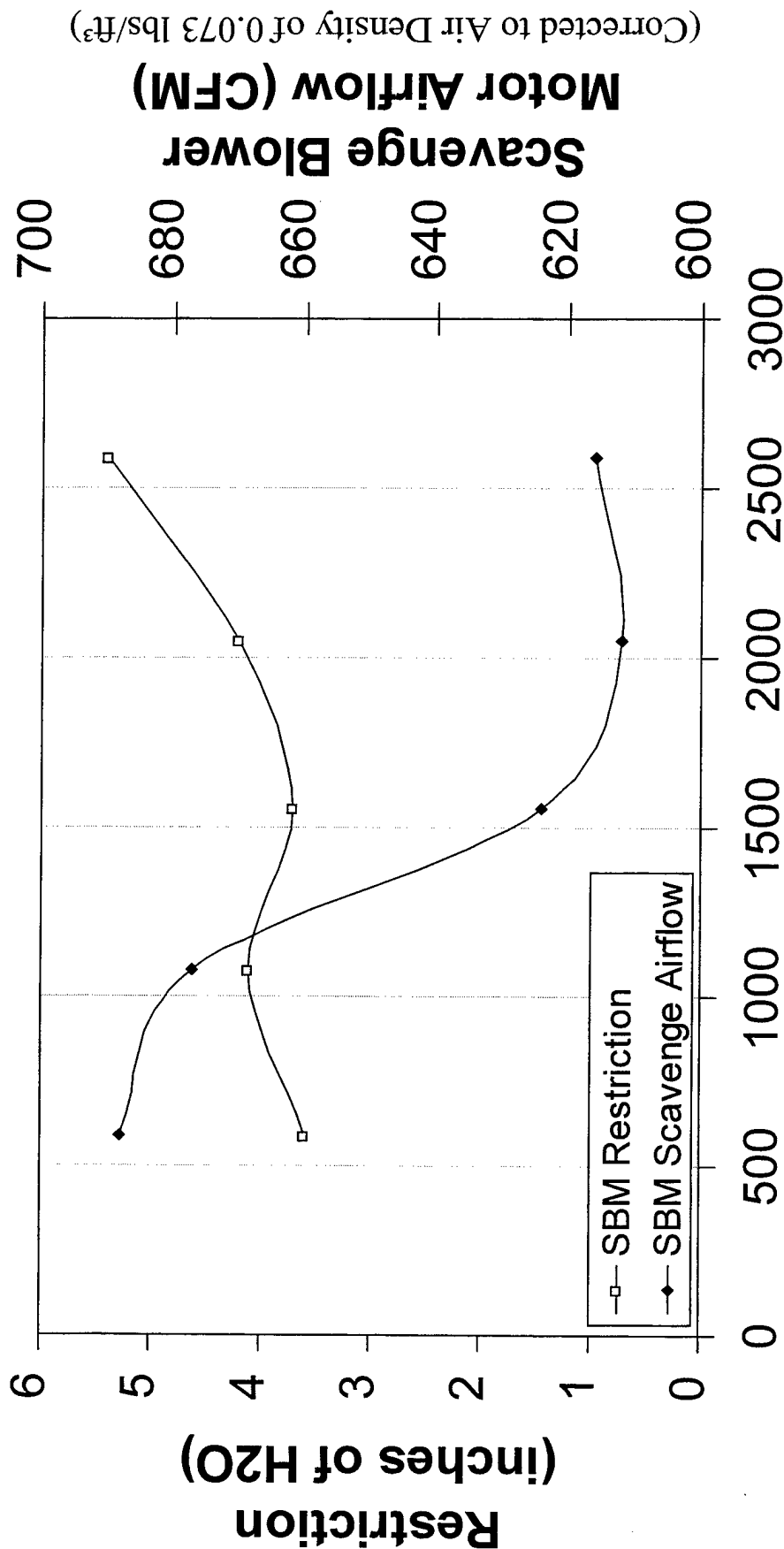
NOTES: 1. Normally all B4/upstream SBM restrictions are vacuum readings and all after/downstream restrictions are pressure readings.

2. The five asterisks indicate B4/upstream SBM restrictions which were measured as a positive pressure versus a normal vacuum. This occurred at low or a no flow condition through SBM. It is believed that damper valve positioned downstream of SBM, caused an airflow reversal on inlet side of SBM, when it was closed or nearly closed during SBM high restriction tests on downstream side.

Table 8

Figure 13

Comparison TD II Precleaner Airflow vs. SBM Airflow and Restriction (SBM in 30 inch Mount Location)



Main TD II Precleaner Airflow (CFM)

(Corrected to Air Density of 0.073 lbs/ft³)
Table 3 Test Data

test point which has a slightly higher restriction than at the 1600 cfm TD II pre-cleaner airflow test point. The largest percent increase in restriction of SBM occurs between TD II pre-cleaner airflow's of 2100 and 2650 cfm. The SBM scavenge airflow decreases slightly at low and high TD II pre-cleaner airflow test points. The one exception is at the nominal 2650 cfm (2588 cfm actual) TD II pre-cleaner primary/main airflow test point which has a slightly higher SBM scavenge airflow than at the nominal 2100 cfm (2052 cfm actual) TD II pre-cleaner primary/main airflow test point. The largest decrease in SBM scavenge airflow occurred between the nominal 1100 cfm (1106 cfm actual) TD II pre-cleaner primary/main airflow test point and the nominal 1600 cfm (1557 cfm actual) TD II pre-cleaner primary/main airflow test point.

Figure 14 is a graphical plot of the SBM airflow versus total pressure drop across the SBM. The SBM was installed in the 30 inch mount location for obtaining pressure readings ahead of the SBM. Figure 14 shows TARDEC performance of SBM at primary/main TD II pre-cleaner airflow's of 600 and 2650 cfm. Two sets of curves are shown for each primary airflow to illustrate how the performance curve is influenced by a change in the air density. At 600 cfm nominal primary/main airflow of TD II pre-cleaner the test data points used to plot the curve are shown in Tables 3 through 8. Table 8 (sheet 1 of 3) test data is the reduced airflow of SBM following SBM safety mechanism kick-in after too high a restriction across the SBM has been reached. Tables 8 (sheet 1 of 3) test data shows one test data total pressure drop reading of 7.76 inches of water. This may be a test data point where SBM had not kicked-in since scavenging airflow is more representative of a previous test run at 6.0 inches of water restriction after SBM (Table 7). The actual TD II pre-cleaner main/primary airflow corrected to an air density of .075 pounds per cubic foot is 589 scfm versus the nominal 600 cfm (605 cfm actual average) at an air density of .073 pounds per cubic foot.

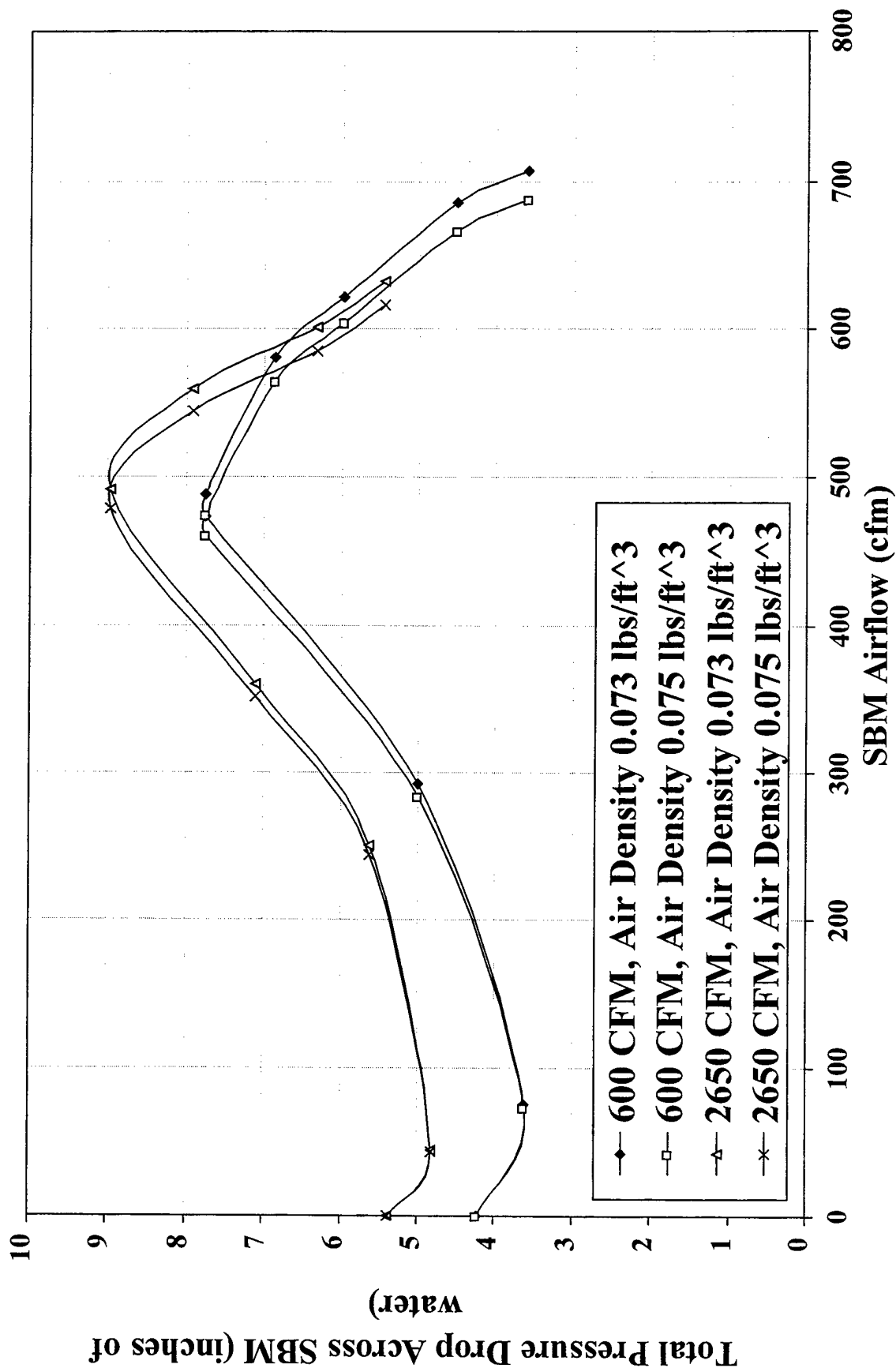
At the nominal 2650 cfm primary/main airflow of TD II pre-cleaner (2588 scfm corrected to an air density of .075 pounds per cubic foot) a higher total restriction across the SBM is observed along with a lower SBM scavenge airflow range. The test data points used to plot the curve in Figure 14 are shown in Tables 3 through 8. Table 8 (sheet 2 of 3 and 3 of 3) is the reduced airflow of SBM following SBM safety mechanism kick-in after too high a restriction across the SBM has been reached. Figure 14 at the nominal 2650 cfm primary/main airflow is somewhat representative of the manufacturer's SBM performance curve shown in Figure 2 however does not match exact flows and restrictions.

4.1.1.2 SBM AIRFLOW RESTRICTION TESTS (CLOSE MOUNT)

Table 9 shows the performance data of the SBM when close mounted to the TB II pre-cleaner scavenging outlet duct. Table 9 test data shows after 1.5 inches of water restriction is reached on the outlet side of SBM at a main/nominal airflow of 2650 cfm the safety mechanism kicks-in which reduces the SBM airflow. When Table 2 test data (30 inch mount location) is compared to Table 9 test data (close mount) one can see the

Figure 14

Pressure Drop vs. SBM Airflow



SBM AIRFLOWS AT VARIOUS RESTRICTIONS (CLOSE MOUNTED)

NOMINAL MAIN AIRFLOW (CFM)	SBM, CFM @ "0" INCH H ₂ O RESTR	SBM, CFM @ "1.5" INCH H ₂ O RESTR	SBM, CFM @ "3.0" INCH H ₂ O RESTR	SBM, CFM @ "4.5" INCH H ₂ O RESTR	SBM, CFM @ "6.0" INCH H ₂ O RESTR	SBM, CFM @ "7" INCH H ₂ O RESTR	SBM, CFM @ "7" INCH H ₂ O RESTR	SBM, CFM @ "7" INCH H ₂ O RESTR
600	705@ Avg 614 cfm main airflow	711 @ Avg 6100 cfm main flow	671@ Avg 608 cfm main flow	635@ Avg 608 cfm main flow	572@ Avg 612.5 cfm main flow	555@ Avg 611 cfm main flow	240@ Avg 610 cfm main flow (5.4 inch H ₂ O Restr)	453.5@ Avg 609 cfm main flow (7.3 inch H ₂ O Restr)
1100	692 @ Avg 1106 cfm main airflow	655 @ Avg 1108 cfm main flow	607 @ Avg 1102 cfm main flow	566@ Avg 1100 cfm main flow	331 @ Avg 1101 cfm main flow (4.9 inch H ₂ O Restr)	432 @ Avg 1102 cfm main flow (6.7 inch H ₂ O Restr)		
1600	653 @ Avg 1617 cfm main flow	639 @ Avg 1607 cfm main flow	598 @ Avg 1607 cfm main flow	528 @ Avg 1612 cfm main flow	211 @ Avg 1602 cfm main flow (6.2 inch H ₂ O Restr)	61 @ Avg 1606 cfm main flow (10.2 inch H ₂ O Restr)		
2100	615 @ Avg 2101 cfm main flow	627.5 @ Avg 2108 cfm main flow	573 @ Avg 2105 cfm main flow	424 @ Avg 2099 cfm main flow (3.8 inch H ₂ O Restr)	136.5 @ Avg 2108 cfm main flow (4.0 inch H ₂ O Restr)			
2650	579@ Avg 2662 cfm main flow	571 @ Avg 2665 cfm main flow	581 @ Avg 2652 cfm main flow	554 @ Avg 2671 cfm main flow	253 @ Avg 2661 cfm main flow (2.01 inch H ₂ O Restr)	160 @ Avg 2662 cfm main airflow	135 @ Avg 2644 cfm main flow (4.0 inch H ₂ O Restr)	62 @ Avg 2657 cfm main airflow (6.0 inch H ₂ O Restr)
								44 @ Avg 2652 cfm main airflow (8.3 inch H ₂ O Restr)

- NOTES:
- SBM airflows measured at predetermined restrictions increments of 1.5 inches of H₂O, up to 6 inches.
 - Where an exact restriction increment of 0, 1.5, 3.0, 4.5, and 6.0 inches of H₂O was not obtained the obtained restriction recorded in parenthesis after the SBM airflow and average main airflow.
 - SBM airflows recorded to the right of (→) indicate where the SBM safety mechanism kicked-in which lowered airflows.
 - The "?" in columns to right of (→) indicates the various restrictions obtained for the five main airflows following SBM safety mechanism kick-in. Restrictions measured are recorded in parenthesis after SBM and main airflows.
 - Actual main airflow cfm's differs from nominal airflows due to averaging of several test runs.
 - Location of restriction reading after/downstream of SBM is shown by arrow (Designated B) in Figure 4.
 - Restriction readings B4/upstream of SBM not taken due to close mount installation. Assume restriction readings would be similar to those obtained in Table 1-6 with SBM in 30 inch mount installation.
 - All airflows measured to an air density of .073 lbs/ft³.

Table. 9

safety mechanism kicks-in at lower restriction numbers on the outlet side of the SBM. This would seem to indicate a higher restriction occurs ahead of the SBM in the close mount position than when the SBM is mounted in the 30 inch mount location. This is because the safety mechanism kicks-in when a total pressure drop of 9.6 inches of water is reached across the SBM (according to SBM manufacturer's data, Figure 2) and the total restriction is a summation of the restriction measured ahead of and after the SBM. If higher restrictions numbers occur ahead of the SBM in the close mount position than in the 30 inch mount location then there is the possibility that an increased turbulent airflow is created just ahead of the SBM when close mounted which could create a combination of static and velocity pressures making the 9.6 inches of water trigger point occur much earlier. This is one explanation as to why the safety mechanism trigger point occurred at different restriction numbers on outlet side of SBM (close mount versus 30 inch mount positions) but did not significantly effect the SBM airflow values between SBM close mount and 30 inch mount locations. In a related matter, the positioning of the SBM (close versus 30 inch) seem to have very little effect on restrictions values obtained across the TD II pre-cleaner.

4.1.2 TURBODYNE II (TD II) PRECLEANER RESTRICTION TESTS

4.1.2.1 TD II PRECLEANER RESTRICTION TESTS (30 INCH MOUNT LOCATION)

Table 10 shows the restriction testing of the TD II pre-cleaner with the SBM in the 30 inch mount location. There was no restriction on the SBM outlet tube and tests were conducted with no dust feed. The TD II pre-cleaner reached a maximum restriction of 10.4 inches of water at a 2650 cfm main/nominal airflow. In comparison the pressure drop across the SBM was 5.8 inches of water at the same airflow test point. The minimum restriction of the TD II pre-cleaner was 1.8 inches of water and it occurred at a 600 cfm main/nominal airflow.

4.1.2.2 TD II PRECLEANER RESTRICTION TESTS (CLOSE MOUNT)

Table 11 shows the restriction testing of the TD II pre-cleaner with the SBM in the close mount location. Restriction tests were run up to a nominal airflow of 3600 cfm and there was no restriction on the SBM outlet duct. The TD II pre-cleaner reached a maximum restriction of 11.25 inches of water at a 2650 cfm main/nominal airflow. This is only slightly higher than the maximum restriction recorded with the SBM installed in the 30 inch mount location (11.25 inches of water versus 10.4 inches of water). The minimum restriction of the TD II pre-cleaner was 1.2 inches of water and it occurred at a 600 cfm main/nominal airflow.

TDII PRECLEANER AIRFLOW VS. RESTRICTION/PRESSURE DROP TEST RESULTS
(SBM 30 INCH MOUNT)

NOMINAL AIRFLOW (CFM)	ACTUAL AVG. AIRFLOW (CFM)	SCAVENGE BLOWER MOTOR (CFM)	PRECLEANER RESTRICTION INCHES OF H ₂ O	PRESSURE DROP ACROSS SCAVENGE BLOWER MOTOR INCHES OF H ₂ O	RELATIVE HUMIDITY/TEMP %/°F
600	605	707	1.8	3.6	28.4 / 75.5
1100	1106	696	2.4	4.1	33.2 / 74.9
1600	1600	641	4.7	3.7	31.7 / 83.6
2100	2108	629	7.3	4.2	30.7 / 83.3
2650	2659	633	10.4	5.8	29.9 / 77.5

NOTES:

1. Scavenge blower motor mounted 30 inches from precleaner.
2. See Figure 2 for SBM mount location and instrumentation location.
3. No restriction on scavenge blower motor outlet.
4. Airflows corrected to density of .073 lbs per cu. ft.
5. No dust feed.
6. 2650 airflow test results is average of three separate test runs.

Table 10

TDII PRECLEANER AIRFLOW VS. RESTRICTION/PRESSURE DROP TEST RESULTS
(S BM CLOSE MOUNT)

NOMINAL AIRFLOW (CFM)	ACTUAL AVG. AIRFLOW (CFM)	SCAVENGE BLOWER MOTOR (CFM)	PRECLEANER RESTRICTION (INCHES OF H ₂ O)	AVERAGE RELATIVE HUMIDITY (PERCENT)	AVERAGE AIR TEMP ° F
600	614	705	1.2	37.8	72.9
1100	1104	692	2.5	40.0	73.5
1600	1617	653	4.6	39.2	74.9
2100	2101	615	7.3	30.7	80.6
2650	2665	571	11.25	29.9	80.7
3100	3096	535	14.8	29.6	79.6
3600	3601	518	18.8	37.9	75.7

- NOTES: 1. Scavenge blower motor close mounted to precleaner.
2. See Figure 3 for sketch of test set-up.
3. No restriction on scavenge blower motor outlet.
4. Airflows corrected to density of .073 lbs per cu. ft.
5. No dust feed

Table 11

4.2 TD II PRECLEANER EFFICIENCY TESTS

4.2.1 TD II PRECLEANER EFFICIENCY, PTI FINE TEST DUST

The PTI fine test dust efficiency results are shown in Table 12. TD II pre-cleaner efficiency test were ran at main/nominal clean airflow's of 600, 1100, 1600, 2100 and 2650 cfm and corrected to an air density of .073 pounds per cubic foot. The highest efficiency was obtained at the lowest main airflow of 600 cfm. The two efficiency tests conducted at 600 cfm had an average efficiency of 96.95 %. The lowest efficiency was obtained at the highest main airflow of 2650 cfm. The two efficiency tests conducted at 2650 cfm had an average efficiency of 94.15 %. Table 12 test data generally shows the TD II pre-cleaner efficiency is highest when the SBM airflow is at the highest percentage of the TD II pre-cleaner main airflow. For example, at 600 cfm main airflow of TD II pre-cleaner the SBM scavenge airflow averages 114 % of the main airflow or 686.5 cfm. In comparison, at 2650 cfm main airflow of TD II pre-cleaner the SBM scavenge airflow averages 22.2 % of the main airflow or 585.5 cfm. TD II pre-cleaner efficiency at 1600 and 2100 cfm main airflow are nearly equal with a slightly higher efficiency at 2100 cfm (94.595 %) than at 1600 cfm main airflow (94.455 %). Figure 15 is a graphical plot of the TD II pre-cleaner efficiency on PTI fine test dust. Test results show a general decrease in TD II pre-cleaner efficiency as the TD II pre-cleaner main airflow increases.

4.2.2 TD II PRECLEANER EFFICIENCY, PTI COARSE TEST DUST

The PTI coarse test dust efficiency results are shown in Table 13. TD II pre-cleaner efficiency tests were ran at main airflows of 600, 1100, 1600, 2100 and 2650 cfm. The highest efficiency was obtained at the lowest main airflow of 600 cfm. For the two efficiency tests conducted at 600 cfm the efficiency averaged 98.725 %. The lowest efficiency was obtained at the highest main airflow of 2650 cfm. For the two efficiency tests conducted at 2650 cfm the efficiency averaged 97.54 %. In general, Table 13 shows the higher the SBM scavenge airflow as a percent of the main TD II pre-cleaner airflow the higher the efficiency. The average efficiency for the 10 tests conducted was 98.15 %. In comparison the average efficiency for the 10 tests conducted on PTI fine test dust (Table 12) was 95.12 % which is just over 3 % lower.

Figure 16 shows graphically a plot of the TARDEC efficiencies obtained on PTI coarse test dust for each of the TD II main airflow test points. For comparison purposes, Figure 16 also shows a plot of the efficiencies obtained by SwRI during their particle size determination tests. Two main differences in testing methods between the two test sites included the following: (1) SwRI ran at a constant 20 % scavenging airflow based on the 2600 cfm maximum airflow of the TD II pre-cleaner. Thus a constant 520 cfm scavenging airflow was used for all five TD II pre-cleaner airflow test points, and (2) the dust feed rate used by SwRI (.025 grams per cubic foot) was 10 % higher than the dust feed rate used by TARDEC. The only test point where the scavenging flow rate was nearly equal between the two test sites was at the 2650/2600 cfm maximum airflow rating of the TD II pre-cleaner. TARDEC maintained a scavenging airflow of 22 % whereas

TDII PRECLEANER EFFICIENCY, PTI FINE TEST DUST

NOMINAL CLEAN/MAIN AIRFLOW (CFM)	SCAVENGE AIRFLOW, (CFM)	SCAV AIRFLOW PERCENT OF MAIN AIRFLOW, (%)	PRECLEANER RESTRICTION INCHES OF H ₂ O	HUMIDITY (%)	EFFICIENCY (%)	EFFICIENCY AVG (%)
600 [600]	675	112.5	1.0	31.7	97.08	} 96.95
600 [604]	698	115.6	1.0	41.8	96.82	
1100 [1097]	692	63.1	2.4	35.6	95.84	} 95.465
1100 [1098]	671	61.1	2.6	24.1	95.09	
1600 [1591]	673	42.3	4.6	35.6	94.19	} 94.455
1600 [1593]	664	41.7	4.7	33.9	94.72	
2100 [2097]	634	30.2	7.4	37.7	94.78	} 94.595
2100 [2097]	643	30.6	7.25	39.1	94.41	
2650 [2640]	590	22.3	11.1	32.5	94.12	} 94.15
2650 [2638]	581	22.0	11.25	37.1	94.18	

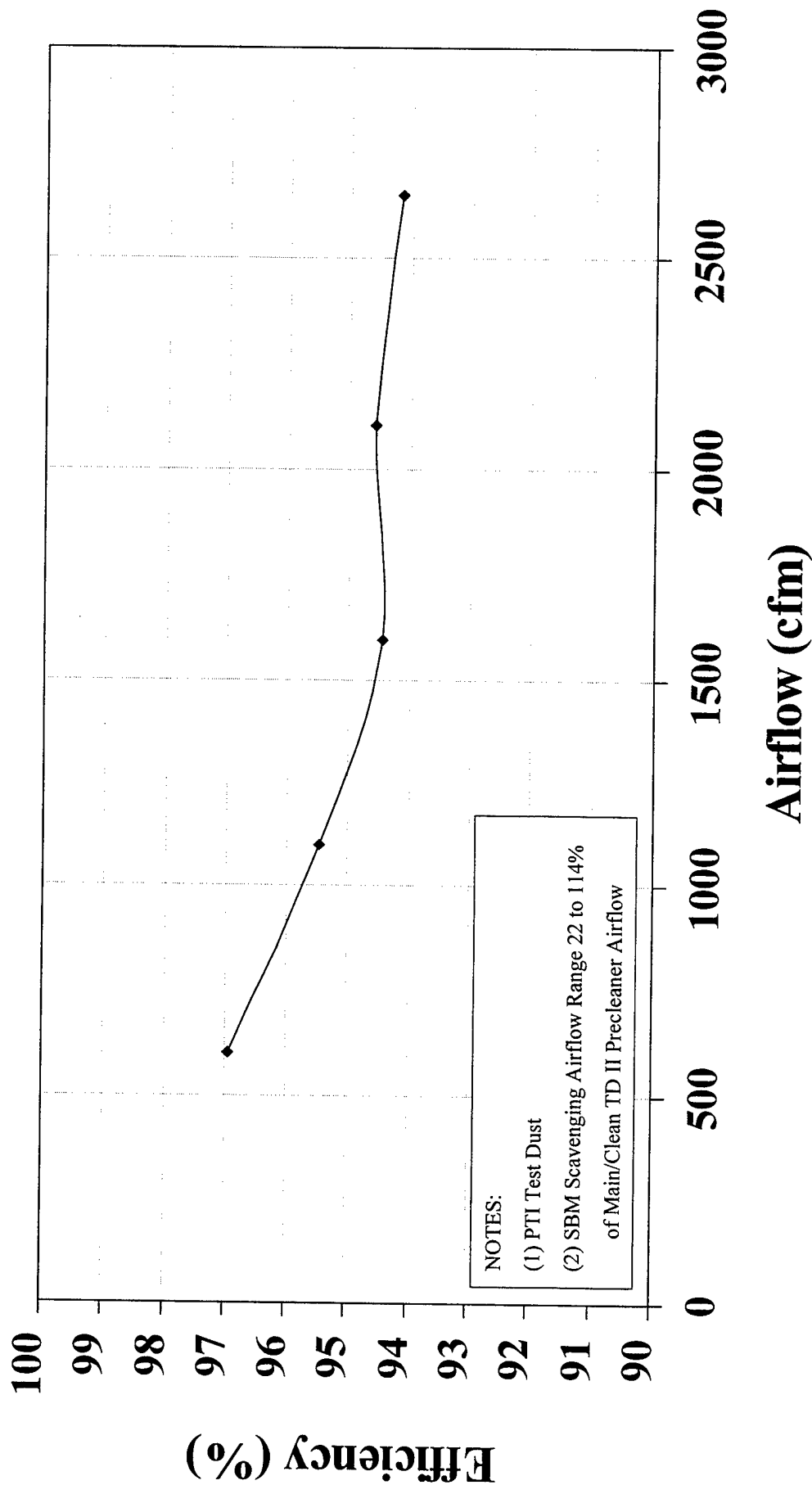
95.12 AVG

NOTES:

1. SBM positioned in close mount installation.
2. Tested with no restriction on SBM, however, range for all tests between -.06 and +.06 inches of H₂O.
3. Airflows corrected to density of .073 lbs per cu. ft.
4. Test dust per SAE J726 test code.
5. [] is average of clean/main airflows recorded during tests.
6. Scavenge airflows were also averaged during tests.

Table 12

FIGURE 15: TD II Precleaner Fine Dust
Efficiency Test Results



(Corrected to Air Density of 0.073 lbs/ft³)

TDII PRECLEANER EFFICIENCY, PTI COARSE TEST DUST

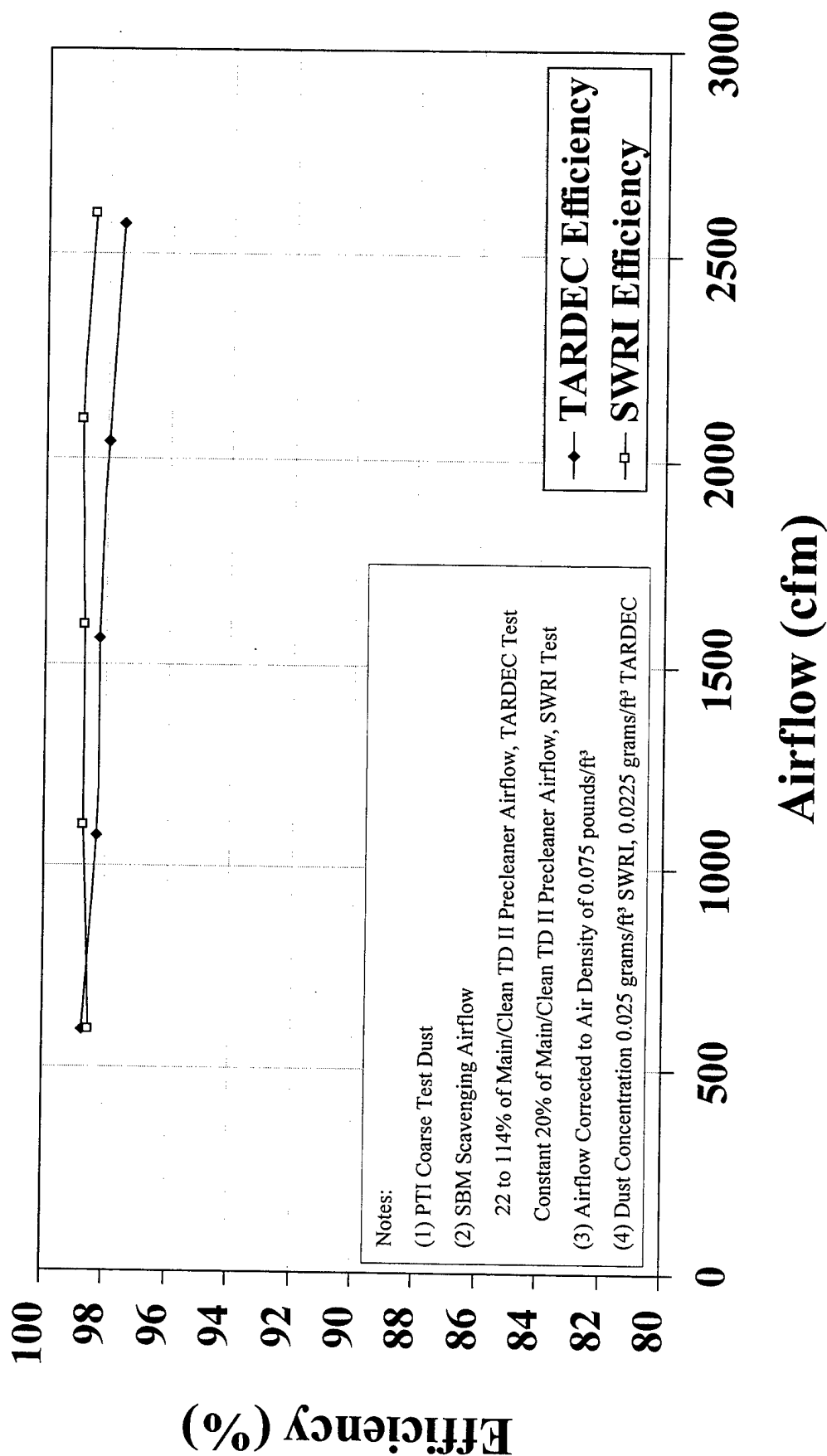
NOMINAL CLEAN/MAIN AIRFLOW (CFM)	SCAVENGE AIRFLOW, (CFM)	SCAV AIRFLOW PERCENT OF MAIN AIRFLOW, (%)	PRECLEANER RESTRICTION INCHES OF H ₂ O	HUMIDITY (%)	EFFICIENCY (%)	EFFICIENCY AVG (%)
600 [612]	702	114.7	1.1	31.4	98.57	} 98.725
600 [608]	685	112.7	1.0	37.1	98.88	
1100 [1109]	683.5	61.6	2.4	32.6	98.57	} 98.295
1100 [1091]	680	62.3	2.3	27.0	98.02	
1600 [1612]	663	41.1	4.4	14.4	98.30	} 98.24
1600 [1602]	682	42.6	4.65	39.6	98.18	
2100 [2110]	629	29.8	7.35	32.8	97.92	} 97.96
2100 [2082]	618	29.7	7.4	31.4	98.00	
2650 [2644]	582	22.0	11.2	36.2	97.48	} 97.54
2650 [2639]	589	22.3	11.3	28.1	97.60	
						98.15 AVG

NOTES:

1. SBM positioned in close mount installation.
2. Tested with no restriction on SBM, however, range for all tests between +.18 and -.10 inches of H₂O.
3. Airflows corrected to density of .073 lbs per cu. ft.
4. Test dust per SAE J726 test code.
5. [] is average of clean/main airflows recorded during tests.
6. Scavenge airflows were also averaged during tests.

Table 13

FIGURE 16: TD II Precleaner Coarse Dust Efficiency Results



SwRI maintained a 20 % scavenging airflow rate. The PTI coarse test dust efficiencies obtained by SwRI are shown in Appendix G, Page G-4. In general, SwRI obtained a higher overall efficiency than TAREDC. The largest differences in efficiencies occurred at TD II pre-cleaner airflow's of 2100 and 2600/2650 cfm. At these test points TARDEC efficiencies were nearly 1 % lower than obtained by SwRI. The TD II pre-cleaner manufacturer showed an average efficiency of 98.28 % for two tests they had conducted on SAE coarse test dust.

4.2.3 TD II PRECLEANER EFFICIENCY, SPECIAL TESTS

Following PTI fine and coarse dust tests, 5 separate efficiency tests were conducted. Two test runs were made for each of the 5 separate efficiency tests. Test results for the 5 separate efficiency tests are shown in Table 14. The 10 total efficiency tests were conducted at a main/nominal airflow of 2650 cfm. Test conditions for each efficiency test are listed under notes in Table 14. The first two tests were conducted on AC fine test dust. SAE J726 Air Cleaner Test Code many years ago but was replaced approximately 5 years ago by PTI test dust used AC test dust. The air cleaner test team goal was to see if there would be significant changes in efficiencies between AC and PTI test dust. Test results showed for the two tests conducted on AC fine test dust an average efficiency of 91.39 % was obtained. This compares to an average efficiency of 94.15 % with PTI fine test dust. This represents a 2.76 % higher efficiency with PTI fine test dust and is considered a significant difference however does not warrant any action be taken.

The next two efficiency tests conducted were with AC coarse test dust. This test dust like AC fine is obsolete and not available through SAE. Efficiency test results on AC coarse test dust showed an average efficiency of 97.61 % compared to an average efficiency of 97.54 % with PTI coarse test dust. This comparison shows that efficiencies with AC and PTI coarse test dust are very similar. Thus, comparisons between AC fine and PTI fine test dusts are vastly far apart whereas comparison between AC coarse and PTI coarse test dusts are nearly identical.

The next four tests were conducted on PTI coarse test dust with fixed scavenging flow rates on SBM of 15 and 10 % respectively. The purpose of these tests was to show how efficiency is reduced when the scavenging airflow rate is decreased. The Turbodyne II pre-cleaner manufacturer specifies a 20 % scavenging airflow rate to meet the required efficiency of 98 %. In all previous efficiency tests, the TARDEC airflow test team maintained a "zero" backpressure on the outlet/downstream side of SBM. However, in real world situations, the vehicle developer may not be able to install an air cleaner system exactly as the air cleaner designer hoped. For example a 20 % scavenging airflow rate at "zero" back pressure on SBM is acceptable, however if a restriction is placed on SBM outlet duct due to vehicle developer installation tradeoffs, SBM performance could be effected through a reduced airflow. This would require a more powerful SBM to compensate for the added restriction to bring the scavenging airflow back to the required 20 %.

TDII PRECLEANER EFFICIENCY, SPECIAL TESTS

NOMINAL CLEAN/MAIN AIRFLOW (CFM)	SCAVENGE AIRFLOW, (CFM)	SCAV AIRFLOW PERCENT OF MAIN AIRFLOW, (%)	PRECLEANER RESTRICTION INCHES OF H ₂ O	HUMIDITY (%)	EFFICIENCY (%)	EFFICIENCY AVG (%)	TEST CONDITIONS
2650 [2637]	584	22.1	11.2	33.7	91.43	}	AC Fine, Non SAE J726 Test Dust
2650 [2636]	577.5	21.9	11.3	32.65	91.35		
2650 [2643]	588	22.25	11.15	28.7	97.61	}	AC Coarse Non SAE 726 Test Dust
2650 [2622]	579	22.1	11.2	25.0	97.61		
2650 [2644]	393.5	14.9	10.7	41.1	97.34	}	PTI Coarse Test Dust Fixed 15% Nominal Scav
2650 [2631]	401	15.2	10.6	33.0	97.31		
2650 [2637]	264	10.0	10.2	35.0	91.96	}	PTI Coarse Test Dust Fixed 10% Nominal Scav
2650 [2635]	267	10.1	10.3	41.1	93.24		
2650 [2640.5]	582	22.0	11.2	34.6	97.97	}	PTI Coarse Test Dust 30 Inch Mount Location
2650 [2620]	578	22.1	11.3	29.2	97.76		

NOTES:

1. SBM positioned in close mount location except for last two tests.
2. Tested with no restriction on SBM, except for 15 and 10% Scavenge Tests.
3. Airflows corrected to density of .073 lbs per cu. ft.
4. PTI Test Dust per SAE J 726 Test Code.
5. [] is average of clean/main airflows recorded during tests.
6. Scavenge airflows were also averaged during tests.

Table 1.4

Test results at a 15 % scavenging airflow showed an average efficiency of 97.325 % compared to an average efficiency of 97.54 % at a 22.15 % scavenging airflow. The 22.15 % scavenging airflow is the SBM scavenging airflow with "zero" back pressure on SBM outlet duct obtained during TARDEC tests. The 15 % scavenging airflow was obtained by placing an average 2.2 inches of water restriction on outlet duct side of SBM. These comparisons show about a .22 % reduction in efficiency when the scavenging airflow is reduced by 7 %.

Test results at the 10 % scavenging airflow showed a more significant decrease in efficiency. The average efficiency at the 10 % scavenging airflow was 92.60 % which represents nearly a 5 % decrease from the 97.54 % efficiency obtained at the 22.15 % scavenging airflow.

The last two efficiency tests conducted in Table 14 were with SBM located in 30 inch mount location. This provides a comparison with Table 13 test results, which had SBM positioned in close mount location. Table 14 test data shows at 2650 cfm main/nominal airflow of TD II pre-cleaner an average efficiency of 97.865 % was obtained. This compares to an average efficiency of 97.54 % with SBM in close mount location. These comparisons indicate a small efficiency improvement (.32 %) with SBM positioned in 30 inch mount location.

4.2.4 TD II PRECLEANER EFFICIENCY AND PRESSURE DROP COMPARISONS

Efficiency and pressure drop tests were run on the TD II pre-cleaner from three different sources. Appendix D provides the efficiency and pressure drop test results run by the manufacturer. Efficiency and pressure drop/restriction test data run by TARDEC's airflow test team is shown in Table 13. Appendix G, Page G-5 shows the efficiency and pressure drop test results of the TD II pre-cleaner run by SwRI. A comparison of these efficiencies conducted on coarse test dust and pressure drops is shown in Table 15.

Table 15 findings show TARDEC test results achieved less efficiency than both SwRI and manufacturer. The most significant test points where this occurred was at the 2040 to 2100 cfm and 2571 to 2600 cfm primary airflow's. At these airflow's, TARDEC test results did not meet the required 98 % efficiency specified by manufacturer when tested with SBM in both 30 inch mount and close mount positions. An efficiency of 97.54 % was obtained at a primary airflow of 2751 cfm (corrected to an air density of .075 pounds per cubic foot) with SBM in close mount position. An efficiency of 97.865 % was obtained at a primary airflow of 2620 to 2640 cfm (air density .073 pounds per cubic foot) or an average primary airflow of 2560 cfm (air density .075 pounds per cubic foot) with SBM in 30 inch mount location. In contrast, SwRI achieved an efficiency of 98.44 % at a primary airflow of 2600 cfm and the manufacturer achieved an average efficiency of 98.68 % at a primary airflow of 2640 cfm.

Table 1.5. TURBODYNE II PRECLEANER EFFICIENCY AND PRESSURE DROP COMPARISONS

PRIMARY AIRFLOW, SCFM	SwRI EFFICIENCY (%)	SwRI PRESSURE DROP INCHES OF WATER	TARDEC EFFICIENCY (%)	TARDEC PRESSURE DROP (INCHES OF WATER)	MANUFACTURER EFFICIENCY (%)	MANUFACTURER PRESSURE DROP (INCHES OF WATER)
594						
600	98.513	1.15	98.725	1.05		
1070						
1100	98.735	2.62	98.295	2.35		
1564						
1600	98.633	98.624 avg.	98.240	4.52		
2040						
2100	98.800	7.8	97.96	7.37		
2571						
2600	98.440	11.1	97.54	11.25		
2640					98.68	9.6

NOTES:

SwRI

- (1) Constant 20% Scavenging Airflow
- (2) PTI coarse test dust
- (3) Airflow corrected to air density of .075 lbs/ft³

MANUFACTURER

- (1) Scavenging flow rate 19.7%
- (2) SAE coarse test dust
- (3) Airflow corrected to air density of .073 lbs/ft³

TARDEC

- (1) Scavenging airflow rate variable (See Table 13)
- (2) SBM installed, close mount position
- (3) Airflow corrected to air density of .075 lbs/ft³
- (4) PTI coarse test dust

Comparison test data in Table 15 also shows at the 2571 to 2640 cfm primary airflow's, the pressure drop across the TD II pre-cleaner was higher during SwRI and TARDEC tests than during manufacturer tests. The manufacturer's recorded pressure drop was about 1.5 inches of water lower than measured by both SwRI and TARDEC. TD II pre-cleaner pressure drop/restriction was slightly lower (10.4 inches of water versus 11.25 inches of water at 2650 main airflow) during TARDEC testing when the SBM was mounted 30 inches away compared to a close mount installation. The pressure drop of TD II pre-cleaner in 30 inch mount installation ranged from 8.3 to 11.7 inches of water for three tests, which averaged 10.4 inches of water. There may have been an error in the first test which produced a pressure drop of 8.3 inches of water, since the remaining two tests produced pressure drop readings of 11.1 and 11.7 inches of water. It is believed the pressure drop of the TD II pre-cleaner is about the same whether the SBM is in close mounted or 30 inch mount position.

A graphical plot of the TD II pre-cleaner pressure drop/restriction tests for TARDEC and SwRI tests is shown in Figure 17. The test results show the TD II pre-cleaner restriction to be nearly the same between TARDEC's two SBM mounting configurations and SwRI test configuration without a SBM.

4.2.5 TD II PRECLEANER EFF.AND RESTR. COMP. WITH OTHER SYSTEMS

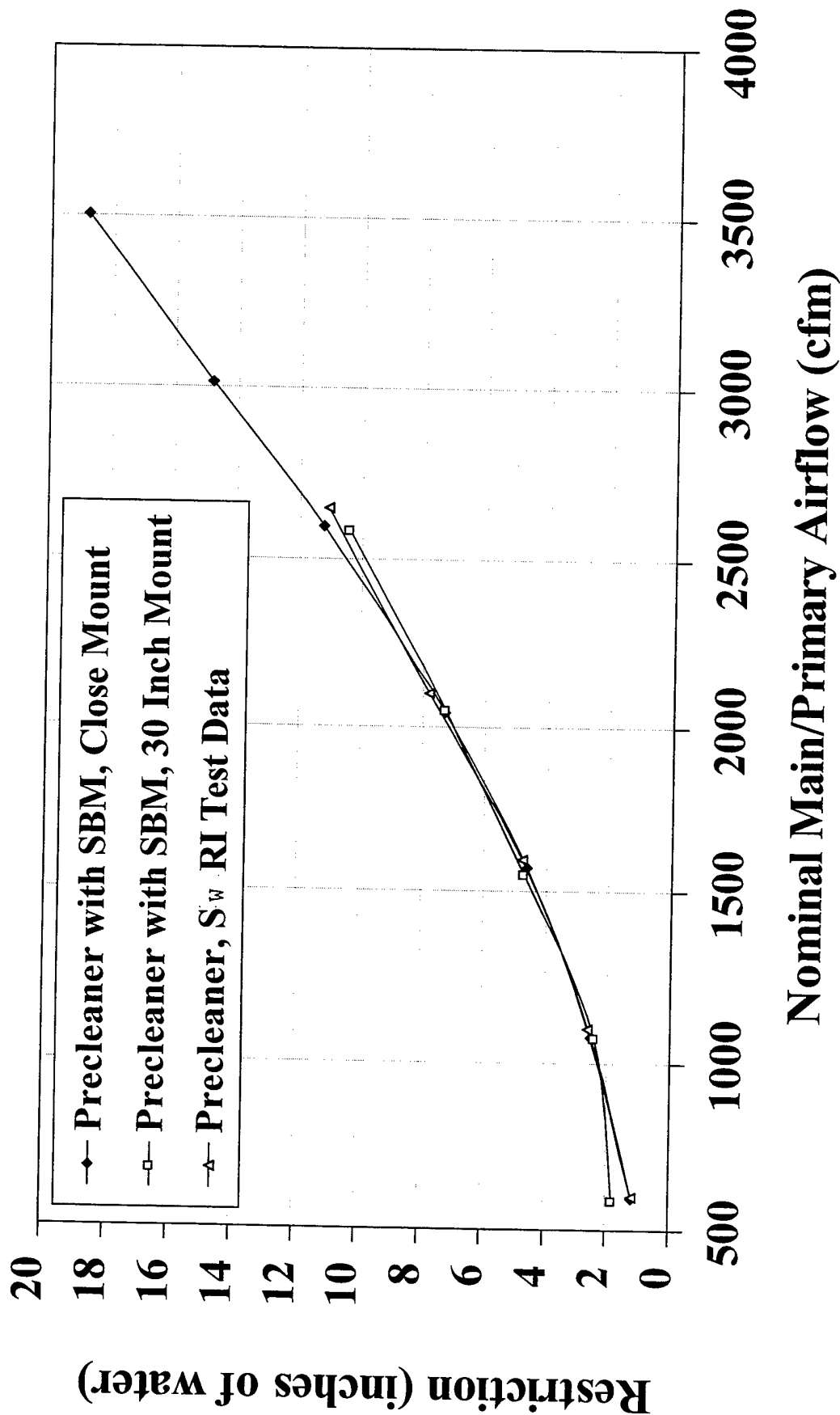
4.2.5.1 TD II PRECLEANER COMPARISON WITH M1 PRECLEANER

Table 16 provides a comparison of the M1 single stage pre-cleaner requirements and the test results obtained on the TD II pre-cleaner. Comparisons show the TD II pre-cleaner increases efficiency nearly 10 % on fine test dust. On coarse test dust the TD II pre-cleaner increases efficiency from 5 to 5.5 % compared to the M1 pre-cleaner. The TD II pre-cleaner restriction is significantly higher (almost 3X) than the M1 pre-cleaner restriction and requires a scavenging airflow at least 2 X greater than the M1 pre-cleaner.

4.2.5.2 TD II PRECLEANER COMPARISON WITH MCG-AC

Table 16 provides a comparison of TARDEC lab tests conducted on MCG-AC with TARDEC lab tests conducted on the TD II pre-cleaner. The MCG-AC is a complete air cleaner system with no barrier filter and employs inertial tubes similar to the TD II pre-cleaner. Comparison test results show the TD II pre-cleaner achieved nearly a 5.5 % higher efficiency than MCG-AC on fine test dust and a 1 % higher efficiency than MCG-AC on coarse test dust. In addition, the MCG-AC had almost a 2 X higher maximum pressure drop than the TD II pre-cleaner through the airflow ranges tested. The scavenging airflow range for the MCG-AC was estimated at 10 to 15 % of the primary/main predicted airflow range whereas the TD II pre-cleaner had a variable scavenging airflow range of from 22 to 114 %. A 22 % scavenging airflow occurred at the maximum airflow test point of the TD II pre-cleaner (2600 to 2650 cfm).

FIGURE 17: TD II Precleaner Airflow vs. Restriction Test Results



(All Airflows Corrected to Air Density of 0.075 lbs/ft³)

Table 16

TDII PRECLEANER EFF AND PRESS DROP COMPARISONS
WITH OTHER PRECLEANER/AIR CLEANERS

<u>COMPONENT</u>	<u>FINE TEST DUST EFF. (%)</u>	<u>COARSE TEST DUST EFF. (%)</u>	<u>PRESSURE DROP (INCHES OF WATER)</u>	<u>SCAVENGIN AIRFLOW (% OF PRIMARY AIRFLOW)</u>
MCG-AC	88.695/90.865 (89.72 AVG)	96.52/98.08 (97.17 AVG)	10 to 20	10 to 15 (Tested at Both 10 & 15)
MCS-AC	97.61/98.93 (98.85 AVG)	99.19/99.71 (99.34 AVG)	10 to 47.2	5 to 15 (Tested at 5, 10 & 15)
M1 PRECLEAN-1 STAGE (Minimum Requirements)	84.5	93.0	3.9	10
M1 PRECLENER PALL FAT 91	84.5/86.5 (85.3 AVG)	93/95.5 (94.5 AVG)	3.9	10
TDII PRECLEANER (TARDEC Test)	94.15/96.95 (95.12 AVG)	97.54/98.725 (98.15 AVG)	1.2 to 11.2	22 to 115
TDII PRECLEANER (SwRI Test)		98.440/98.800 (98.624 AVG)	1.15 to 11.1	20

NOTES:

1. PTI Test Dust
2. Efficiencies averaged across airflow range of component
3. Pressure drop/restriction ranges across airflow range of component
4. TDII Precleaner, TARDEC Test, Scavenge Airflow ranges with unregulated SBM installed, zero restriction on SBM outlet.

4.2.5.3 TD II PRECLEANER COMPARISON WITH MCS-AC

Table 16 provides a comparison of TARDEC lab tests conducted on MCS-AC with TARDEC lab tests conducted on TD II pre-cleaner. The MCS-AC is similar but a smaller air cleaner than the MCG-AC and uses no barrier filter. Comparison test results show the MCS-AC achieved a 3.7 % higher efficiency than the TD II pre-cleaner did when tested on fine test dust. Similarly, the MCS-AC achieved an average 1 % higher efficiency than the TD II pre-cleaner (average efficiency of both SwRI and TARDEC test results) did when tested on coarse test dust.

The MCS-AC had an extremely high pressure drop, which measured over 4 X higher than the TD II pre-cleaner. The 4 X higher number is based on the maximum predicted airflow of the MCS-AC which produced a restriction of 47.2 inches of water compared to a 11.2 inches of water restriction at maximum airflow rating (2600 to 2650 cfm) of TD II pre-cleaner. The scavenging airflow range for the MCS-AC was estimated at 10 to 15 % of the primary predicted airflow whereas the TD II pre-cleaner had a variable scavenging airflow range of from 22 to 114%. The 22 % scavenging airflow occurred at the maximum airflow of the TD II pre-cleaner (2600 to 2650 cfm).

During MCS-AC dust tests, measurements were taken on a restriction tap built into the MCS-/AC scavenging air duct. The restriction at this tap measured 23.1 inches of water at a calculated maximum MCS-AC airflow of 1000 cfm with a scavenging airflow of 10 %. What this seems to indicate is that the scavenging blower motor or another scavenging device to remove dust must be capable of producing 23.1 inches of water differential at a primary airflow of 1000 cfm with a 10 % scavenging airflow. To obtain this high water differential may indicate a large size scavenging system. For comparison, the M1 tank uses a scavenging blower motor, which at a pre-cleaner primary airflow of 10,000 cfm must produce a scavenging airflow of 1000 cfm (10 % scavenging airflow). At these conditions the blower motor must be capable of producing a maximum differential of 10.5 inches of water.

4.2.6 COMPARISON OF PARTICLE SIZE EFFICIENCY

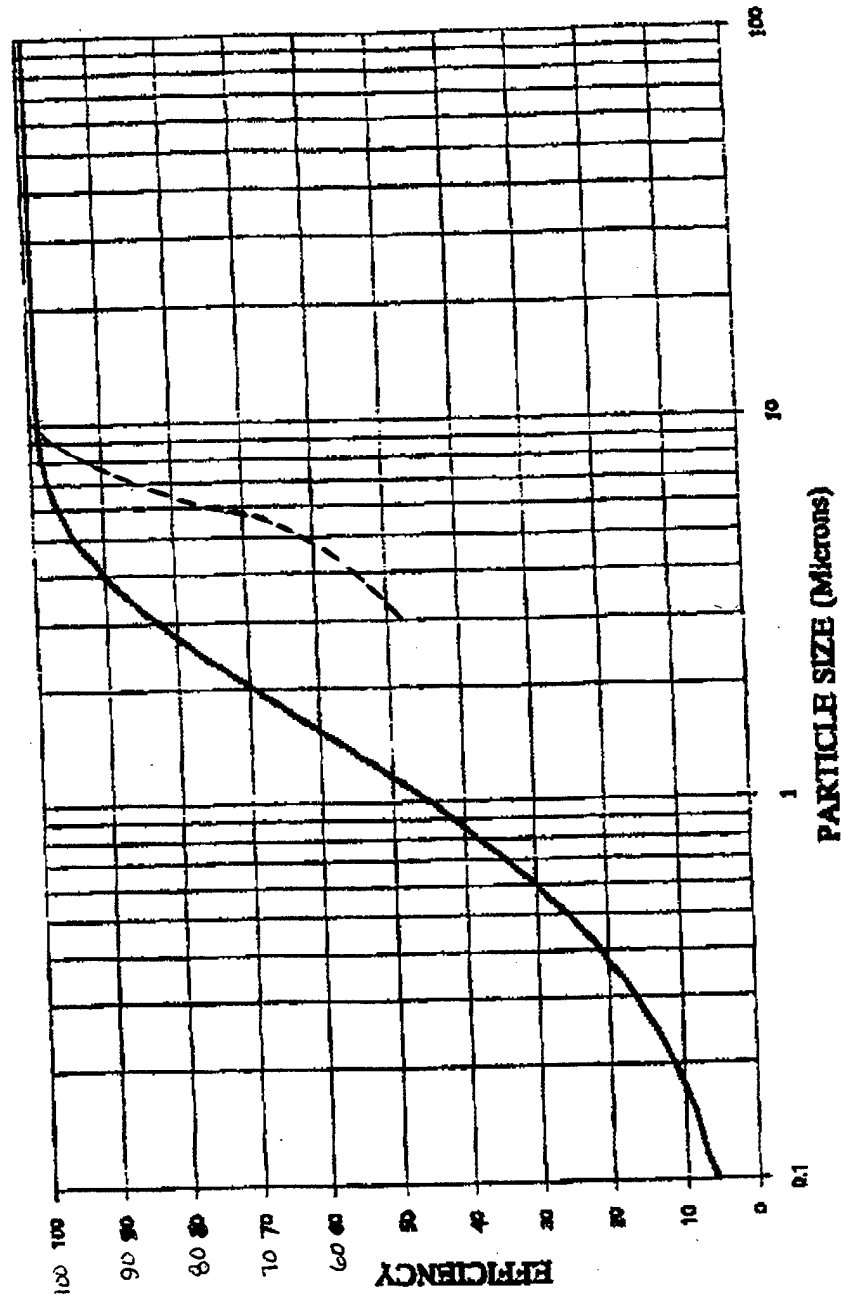
Prior to the start of TARDEC lab tests on the TD II pre-cleaner, Pall Aeropower Corporation provided a graph (Figure 18) on Centrisep particle size efficiency. Pall indicated this curve may have come from old test data and those efficiencies were determined on AC coarse test dust only. Figure 18 also shows the fractional efficiency versus particle size data obtained by SwRI during dust tests in 1997 (Reference Appendix G). SwRI tests were run on PTI coarse test dust. A comparison of test data would seem to indicate for a known particle size a lower efficiency was measured during SwRI tests than during Pall's tests. For example at a particle size of 7 microns, Pall obtained an efficiency of approximately 98 %, whereas SwRI obtained an efficiency of 85 %. It is not known the significance or accuracy of these comparisons or what the lower efficiencies obtained by SwRI means. The data is provided for informational purposes only.

— PALL, TEST DUST, AC COARSE
 - - - SwRI, TEST DUST, PTI COARSE

Centrisep

FIGURE 18:

Particle Size Efficiency



5.0 CONCLUSIONS/RECOMMENDATIONS:

1. During TARDEC efficiency tests the TD II pre-cleaner achieved an overall efficiency of 98.15 % on coarse test dust through the TD II pre-cleaner airflow range (600-2650 cfm). This was about .5 % less efficiency (98.62 % vs. 98.15 %) than obtained by SwRI during their testing on PTI coarse test dust. The largest differences in efficiencies between TARDEC and SwRI tests for specific airflow test points occurred at the higher airflow test points (2100 and 2600/2650 cfm) where TARDEC's efficiency on PTI coarse test dust was nearly 1 % lower than SwRI.
2. Different mounting locations of the SBM (close mount vs. 30 inch mount) appear to affect the time it takes to reach the maximum total pressure drop across the SBM where the relief/safety valve kicks in. For the same airflow test points the SBM in close mount position reaches the maximum total pressure drop limit of approximately 9.6 inches of water sooner than when the SBM is located in the 30 inch mount position. This results in the SBM relief or safety valve to trigger sooner when SBM is close mounted which reduces the SBM airflow quicker as shown in manufacturer's cyclic curve (Figure 2). The SBM airflow is not reduced as quick when the SBM is located in the 30 inch mount position. When the SBM is close mounted, there may be increased turbulence ahead of the SBM due to interactions of the TD II pre-cleaner causing both static and velocity pressures, which account for quicker increases in the total pressure build up.
3. During TARDEC pressure drop/restriction tests the TD II pre-cleaner pressure drop/restriction increased somewhat proportional to the TD II pre-cleaner main/primary airflow. The highest pressure drop/restriction occurred at the maximum main/primary airflow of 2650 cfm and measured 11.25 inches of water with SBM in close mount position and 10.4 inches of water with SBM in 30 inch mount location. These pressure drop/restriction readings are approximately the same that was recorded during SwRI particle size determination testing. SwRI obtained a maximum pressure drop/restriction of 11.1 inches of water at a main/primary airflow of 2600 scfm.
4. In Appendix G, SwRI particle size determination testing on the TD II pre-cleaner revealed the following findings:
 - a. Geometric efficiency exceeded efficiency predicted by the particle size data with an average difference of 2.07 %. This difference is expected and was probably caused by combination of factors such as physics of measurement and the dynamics of particle separation and transports.
 - b. Downstream mass distributions were very nearly log-normal, having a mass median geometrical diameter for all test conditions of about 5 to 6 microns.
 - c. For three specific upstream dust concentrations of 0.00625, .0125 and .025 grams per cubic foot (zero visibility) test results showed an inverse dependency on concentration. At lower concentration levels of .00625 grams/cubic foot separation efficiency becomes more sensitive to airflow.

- d. Fractional efficiency calculations at three inlet dust concentrations of 0.025, 0.0125 and 0.00625 grams/cubic foot over an airflow range of 600 to 2600 scfm primary airflow showed: (1) TD II pre-cleaner has an effective cut size from 3 to 6.5 microns depending on the concentration and airflow rate. The cut size is the particle size where the probability of particle collection is 50 %. (2) For the three inlet dust concentrations collection efficiency was 90 % or better at 10 microns and 99 % better at 15 microns.
5. It is recommended that the SAE J 726 Air Cleaner Test Code establish test procedures to assure that the dust feed rate among testing communities is the same. Variations in the dust feed rate to the TD II pre-cleaner was observed between TARDEC, SwRI and the TD II pre-cleaner manufacturer. This may not be significant for pre-cleaner testing but would be more critical for air cleaner tests using barrier filters.

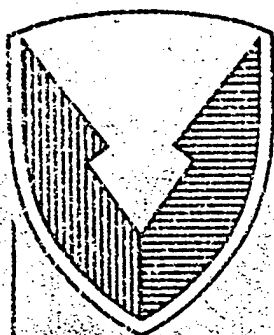
APPENDIX A

EVALUATION OF THE TURBODYNEtm II
SELF-CLEANING AIR FILTRATION SYSTEM
ON A KNOWN MILITARY ENGINE

RD & E

C E N T E R

Technical Report



No. 13358

EVALUATION OF THE TURBODYNE™ II
SELF-CLEANING AIR FILTRATION SYSTEM ON
A KNOWN MILITARY ENGINE

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12. PERSONAL AUTHOR(S) Lemmo, Alfred C.				
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19. ABSTRACT (Continue on reverse if necessary and identify by block number) The concept of a new type of self-cleaning air filtration system was demonstrated and evaluated. The system acquired significant advantages in volume, performance and logistics considerations by placement of the self-cleaning stainless steel barrier filter downstream of the turbocharger. The pressurized air within the barrier filter was used to blow back and clean the filter medium. Adequate protection of the turbocharger compressor wheel from dust erosion was accomplished by the highly efficient inertial precleaner alone. The precleaner was shown to be effective even at low airflow rates and high dust loads; the overall system completed 200 hours of operation on a Cummins VTA-903 using a modified SAE J726 test cycle at zero visibility without developing excessive restriction.				
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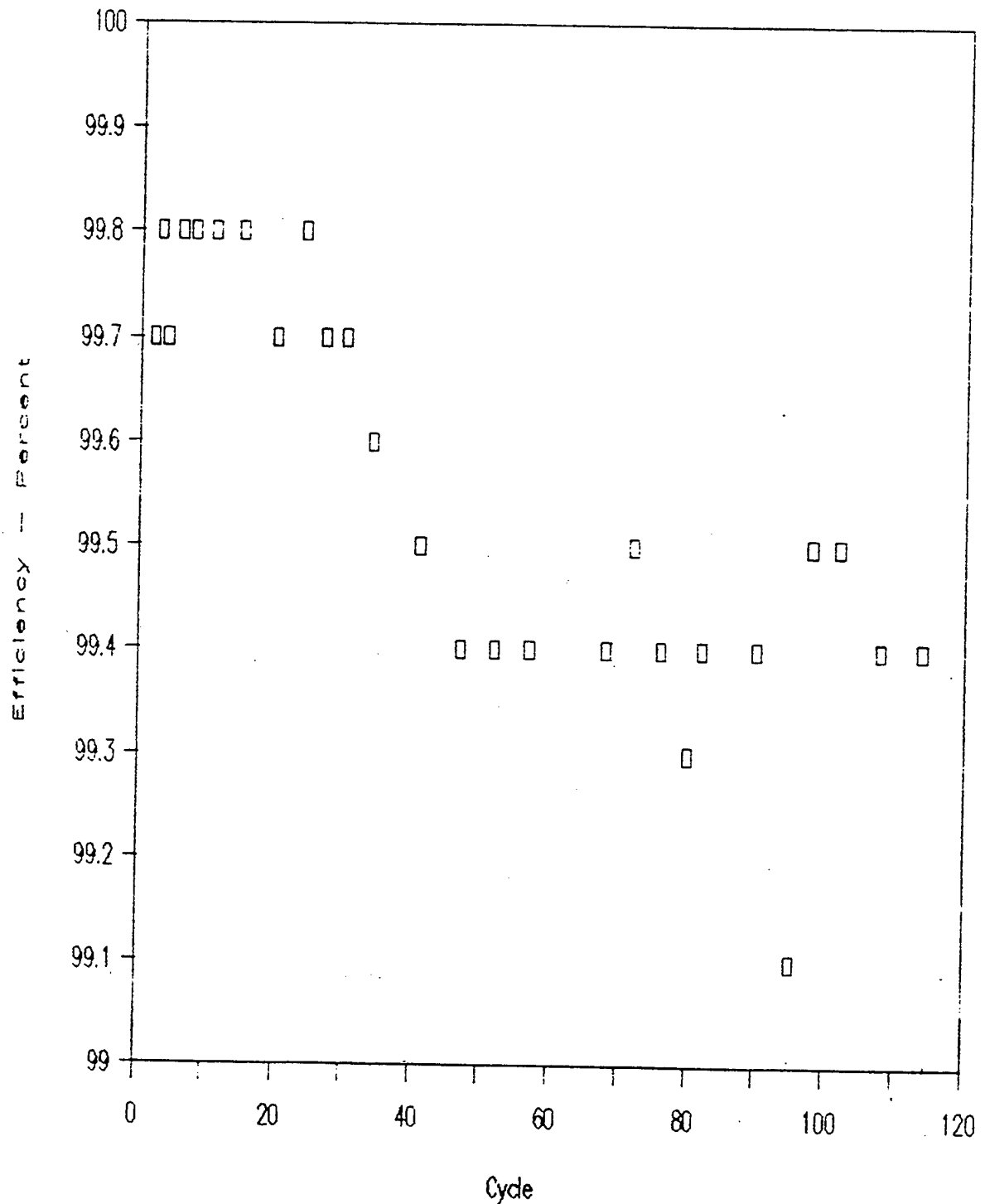
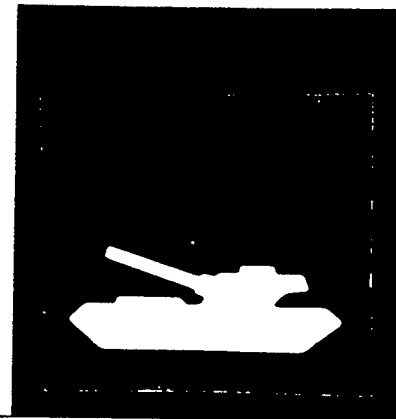


Figure 5-30. Filtration Efficiency

APPENDIX B

OPERATION DESERT STORM (ODS)
SELF CLEANING AIR FILTER (SCAF) SYSTEM
FOR M 88A1 VEHICLE AND AVDS 1790-2DR ENGINE



**U.S. ARMY TANK- AUTOMOTIVE COMMAND
TANK-AUTOMOTIVE TECHNOLOGY DIRECTORATE**

WARREN, MICHIGAN

FINAL REPORT

**OPERATION DESERT STORM (ODS)
SELF CLEANING AIR FILTER (SCAF) SYSTEM
FOR M88A1 VEHICLE AND AVDS1790-2DR ENGINE**

**CONTRACT NO. DAAE07-92-C-R069
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PREPARED BY
 **TELEDYNE VEHICLE SYSTEMS**
76 GETTY STREET • MUSKEGON, MICHIGAN 49442

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ABSTRACT

This program, Phase I, was initiated to evaluate the M88A1 vehicles air induction system due to the high failure rate, caused by dust ingestion, observed during Operation Desert Storm (ODS). Failures occurred, in part, due to air induction hose clamps loose/missing, deteriorated hose material, air filter elements with holes through the media or elements missing. These incidents caused the AVDS1790-2DR engines to accept dust laden air for combustion which causes piston/piston ring failures and subsequently catastrophic engine failures. These type of failures directly reduced the mission readiness and vehicle reliability.

Two (2) SCAF System Proposals, Donaldson Incorporated Pulse Jet Air Cleaner (PJAC) System and Pall Aeropower Corporation (PAC) Turbodyne II™ System, were evaluated with the PAC Turbodyne II™ System selected in conjunction with TACOM for prototype development. This system was selected for its best solution for reliability improvements and would provide the highest cost return as a retrofit of the M88A1 Vehicle based on Teledyne Vehicle System (TVS) and Lambda Corporation performing an economic analysis of both systems. (See Attachment A)

Design work, on the system, was initiated in August 1995 by both TVS and PAC with component parts placed on order in March 1995. The system installation was accomplished in August 1995 and initial "Shakedown" running found the system functional. The 200 mile scheduled dust testing was initiated on TVS's Test Track and with 108.3 miles completed. After 30.7 miles two incidents occurred, dust detectors activated and barrier filter delta pressure indicators activated. Corrective action was taken and testing continued. At 83.3 miles the blowback valve was found to be stuck open causing the engine low on power an excessive smoke. PAC was notified and the system components were removed and shipped to PAC for investigation and system bench testing to determine cause of the condition. Corrective Action was taken on the blowback valves and the system components were returned to TVS to continue the dust testing. After an additional 25 miles, the dust testing was terminated at TVS due to weather conditions (snow/rain) and the components were returned to PAC for their scheduled 200 hour bench testing. PAC testing was terminated after approximately five hours when it became apparent that the filter elements differential pressure increase rate exceeded the cleaning capability of the barrier system. This condition will cause a condition which would lead to engine stall for lack of sufficient intake air.

Although the 200 hour bench testing phase of the program has been terminated, PAC will continue to investigate and correct the condition which prohibits the effective cleaning of the media. (See Attachment B)

Two scheduled program activities were not conducted, 1) 200 hours of dynamometer testing at zero visibility dust conditions with the SCAF system and 2) engine mounted SCAF system water submergence test per MIL-E-62177. These two scheduled activities were negated due to the late component delivery schedule. It was felt that the vehicle dust testing activity took priority to ensure system function under actual fielded conditions.

APPENDIX C

EG & G INFO ON VANEAXIAL FANS

CHAPTER XII

CALCULATION OF THE NORMAL AXIAL-FLOW FAN

76. GENERAL REMARKS

The designation "axial-flow fan" like the designation "radial-flow fan" originates from the main flow path through the rotor. The rotor is in the path of the axis of rotation. Accordingly, the rotor consists of a hub which is fitted with aerofoils in a radial direction. The aim in the design is to profile these aerofoils in such a way that all air particles are given the increase in energy and the unavoidable losses are kept as low as possible.

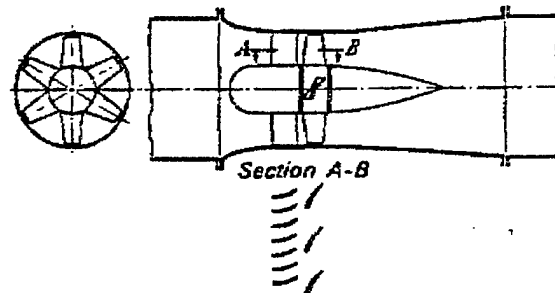


FIG. 216. Diagram of an axial-flow fan.

In general application, the fan, according to Fig. 216, becomes the "armature of a duct". By its introduction into a duct the axial-flow fan simplifies the design. This is because owing to the basically axial-flow path, the fan forms the part of the duct externally.

The following components are mainly present in axial-flow fans:

- (1) A piece of duct constricted into a nozzle and a duct expanded into a diffuser. In many cases, in the interests of efficiency and convenience, it is necessary for the diameter of the rotor to be less than that of the duct.
- (2) Rotor consists of a hub and aerofoil blades, the number of which generally varies from 4 to 8. The limits lie between 2 and 50 blades.
- (3) Upstream and downstream guide vanes.

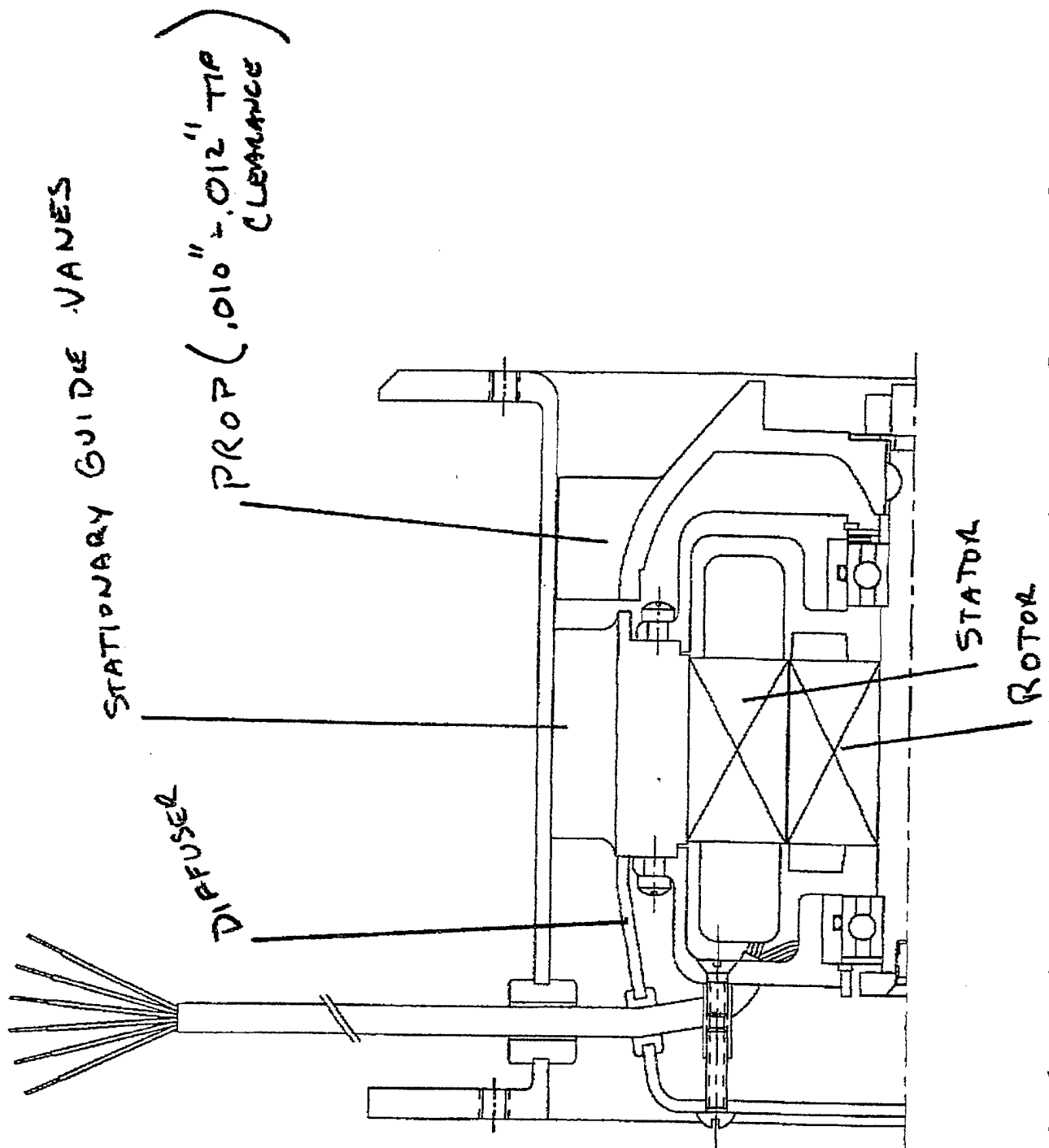
As the flow through the fan is symmetrical to the axis, uniform flow conditions will be encountered on any random section of the cylinder. Therefore it is advisable to develop this cylinder on a plane. This is shown in Fig. 216 (at the bottom). Guide vanes and rotor appear here as a cascade of blades of infinite length. Each section of the cylinder therefore will have a different appearance. If we look at the section *AB* close to the hub, cascades of blades are

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FANS

seen, the pitch of which is less than at the periphery, and their blade cross-section—according to length, form, and angle—must look different from there since, of course, the peripheral speed varies from radius to radius. It will be presumed that the flow through the cascade of blades will be the governing factor for the design of fans of this kind. In actual fact the knowledge of the so-called cascade flow is the basis for the whole calculation.

TYPICAL TIP CLEARANCES ON
VANEAXIAL FANS ARE 0.010" - 0.012".



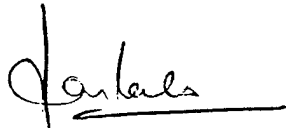
APPENDIX D

MANUFACTURER'S EFFICIENCY AND PRESSURE DROP TESTS
ON MIPS TWO STAGE INERTIAL SEPARATOR

AAI INERTIAL SEPARATOR TESTING

DOCUMENT NO.: CE-00852-1TP
PAC P/N: CE-00852-1D9
CUSTOMER: AAI CORPORATION
DATE: MAY 28, 1997

Prepared by:



Jay Patel, Engineering Supervisor

D. - 2

PALL AEROSPACE COMPANY

A DIVISION OF PALL AEROPOWER CORPORATION

PALL

**EFFICIENCY TESTING
ON
AAI INERTIAL SEPARATOR
FOR
TURBODYNE II SYSTEM**

SCOPE

The two stage Inertial Separator, PAC P/N CE-00852-1D9, used on the MIPS engine was tested for pressure drop and separation efficiency using SAE Coarse test dust.

TESTING

The details of the efficiency tests and pressure drop are as per attached data sheets.

RESULTS

The separation efficiency using SAE Coarse dust was measured at 98.6% and 98.73%, exceeding the 98.0% design requirement. The pressure drop measured was 9.6 in. H₂O.

FED. MFG. CODE

18350

PAGE

PALL

Pall Aerospace Company

A Division of Pall Aeropower Corporation

TEST DATA FOR DUST SEPARATION EFFICIENCY

DATE: 4-21-94

TEST PERFORMED PER: ENGINEERING

TEMPERATURE: 80°F

PART NUMBER: CE00852-1D9

HUMIDITY: 46%

SERIAL NUMBER: A001

PRESSURE: 30.18" Hg

MEASUREMENT EQUIPMENT: (attach additional sheets, if required)

S/N	ITEM	RANGE	ACCURACY	CALIBRATION DUE DATE
291	6" INCLINOMETER	0-6.00" w.c	0.01" w.c	10-31-94
469	6" INCLINOMETER	0-6.00" w.c	0.01" w.c	3-31-95
366	36" MANOMETER	0-36.0" w.c	0.1" w.c	10-31-94

$Q_{\text{FLOW}} =$ 2640 SCFM

$\Delta H_{\text{FLOW}} =$ 1.70" w.c

$Q_{\text{SCAVENGE}} =$ 520 SCFM

$\Delta H_{\text{SCAVENGE}} =$ 1.82" w.c

CONTAMINANT: 1268g SAE COARSE TEST DUST

INGRESSION RATE: 0.024 g/ft³

TOTAL CONTAMINANT = $W_1 =$ 1268g SAE CTD

INITIAL WEIGHT OF MASTER FILTER = $W_2 =$ 405.91g

FINAL WEIGHT OF MASTER FILTER = $W_3 =$ 423.24g

RESULTS:

$$\text{Efficiency} = \left[\frac{W_1 - (W_3 - W_2)}{W_1} \right] \times 100$$

EFFICIENCY = 98.63%

NOTES AND OBSERVATIONS: _____

Technician

Douglas P. Estlin

Manager

[Signature]

D-4

Date

4-21-94

DATE: 4-21-94

TEST DATA FOR DUST SEPARATION EFFICIENCY

TEST PERFORMED PER: ENGINEERING TEMPERATURE: 80°FPART NUMBER: CE 00852 - 1 D9 HUMIDITY: 46%SERIAL NUMBER: A001 PRESSURE: 30.18" Hg

MEASUREMENT EQUIPMENT: (attach additional sheets, if required)

S/N	ITEM	RANGE	ACCURACY	CALIBRATION DUE DATE
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 $Q_{\text{FLOW}} =$ 2640 SCFM $\Delta H_{\text{FLOW}} =$ 1.70" w.c. $Q_{\text{SCAVENGE}} =$ 520 SCFM $\Delta H_{\text{SCAVENGE}} =$ 1.82" w.c.CONTAMINANT: 1268 g SAE COARSE TEST DUSTINGRESSION RATE: 0.024 g / ft³TOTAL CONTAMINANT = $W_1 =$ 1268 g SAECTDINITIAL WEIGHT OF MASTER FILTER = $W_2 =$ 415.74 gFINAL WEIGHT OF MASTER FILTER = $W_3 =$ 431.83 g

RESULTS:

$$\text{Efficiency} = \left[\frac{W_1 - (W_3 - W_2)}{W_1} \right] \times 100$$

EFFICIENCY = 98.73%

NOTES AND OBSERVATIONS: _____

Technician Donalyn PrestonManager
D-5JohnDate 4-21-94

DATE: 4-21-94

TEST DATA FOR AIRFLOW RESTRICTION

TEST PERFORMED PER: ENGINEERINGTEMPERATURE: 80°FPART NUMBER: CE-00852-109HUMIDITY: 46%SERIAL NUMBER: A001PRESSURE: 30.18" Hg

MEASUREMENT EQUIPMENT: (attach additional sheets, if required)

S/N	ITEM	RANGE	ACCURACY	CALIBRATION DUE DATE
291	6" INCLINOMETER	0-6.00" w.c	0.01" w.c	10-31-94
469	6" INCLINOMETER	0-6.00" w.c	0.01" w.c	3-31-95
366	36" MANOMETER	0-36.0" w.c	0.1" w.c	10-31-94

 $Q_{\text{FLOW}} =$ 2640 SCFM $\Delta H_{\text{FLOW}} =$ 1.70" w.c $Q_{\text{SCAVENGE}} =$ 520 SCFM $\Delta H_{\text{SCAVENGE}} =$ 1.82" w.c

RESULTS:

TP1 = N/ATP2 = N/ATP3 = N/A

AIR CLEANER AIRFLOW RESTRICTION =

9.6" w.c

SCAVENGE AIRFLOW RETRICTION =

NOTES AND OBSERVATIONS:

Technician

Douglas Poston

Manager

[Signature]

Date

4-21-94

APPENDIX E

LAB TEST AND EVALUATION OF MIPS
TURBODYNE II SELF CLEANING AIR FILTER

TESTING OF TURBODYNE II CE-00852-1 FOR AAI

1.0 TEST OBJECTIVE

The objective of this testing was to verify two important characteristics of this Turbodyne filtration system.

- 1) Mechanically evaluate this system for the high temperature and high pressure environment. Testing also involves some cyclic temperature testing for thermal expansion and contraction and to obtain limited endurance on system dynamics i.e., the rotator mechanism and the blowback valve assembly.
- 2) To subject the system to SAE fine dust and evaluate the ΔP rise characteristics and establish stabilized system pressure losses. This dust testing is a severe test for the rotating and the blowback mechanism as compared to the actual environmental conditions where, with a 98.6% precleaner, the quality of dust is considerably finer.

2.0 TEST SET-UP

Test set-up was coordinated by Process Equipment Development (PED) and was similar to as outlined for G.K.N. Sankey testing (attached Figure 1). The following test parameters were monitored continuously.

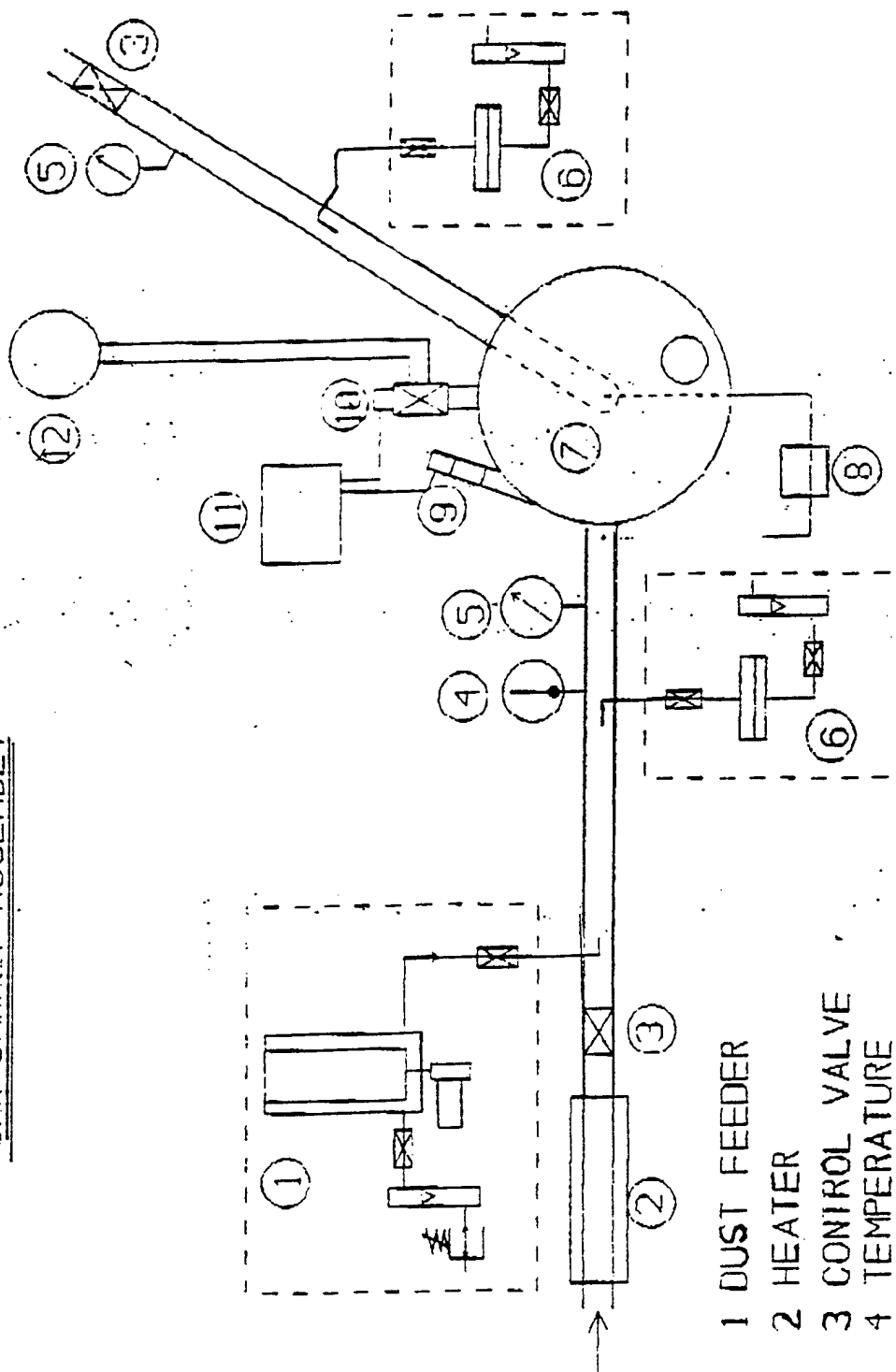
- 1) Total flow to Turbodyne system
- 2) Total pressure at inlet to Turbodyne
- 3) Total pressure at outlet from Turbodyne
- 4) Air temperature at inlet to Turbodyne
- 5) Air temperature at outlet from Turbodyne
- 6) Electrical input to rotator motor and the controller for the blowback mechanism

3.0 TEST PARAMETERS

The Turbodyne II system for AAI has been designed for the following parameters.

Mass air flow rate	3.3 lb/sec
Air temperature	425°F
Air pressure	56 PSIA
Rotator speed	4 RPH
Blowback cycle	8 sec.
Blowback duration	300 msec.

TURBODYNE TEST SCHEMATIC
GKN SANKEY ASSEMBLY



- 1 DUST FEEDER
- 2 HEATER
- 3 CONTROL VALVE
- 4 TEMPERATURE
- 5 PRESSURE
- 6 ISOKINETIC SAMPLER
- 7 GKN SANKEY HOUSING
- 8 DIFFERENTIAL PRESSURE
- 9 ROTATION MOTOR
- 10 BLOWBACK VALVE
- 11 MOTOR CONTROLLER
- 12 DUST COLLECTOR

PALL CORP.
PROCESS EQUIPMENT DEVELOPMENT
S. HATHAWAY 9-30-91

FIG1

Pall Aeropower Corporation

3.0 TEST PARAMETERS - cont'd

Because of the limitation with the current hot gas test facility at PED, the testing was conducted at the 60% rated flow conditions. Also, the 60% flow condition is an average value for an extended dirt capacity test per MIL-STD-62048. These flow conditions are:

Mass air flow rate	1.981 lb/sec
Air temperature	375°F
Air pressure	33 PSIA

The blowback and the rotational mechanism parameters remain constant as defined by the actual design parameters. In all the testing, the rotator and blowback mechanism is kept functionally. The controller for the blowback valve requires a 28VDC power source. The rotator motor also requires a 28VDC supply.

4.0 TESTING

The following tests were conducted using one Turbodyne II housing and two elements.

Test A

1. The flow rate for the Turbodyne system was set at 60% rated condition and the various pressure drop values measured. This testing was repeated using the second element. This is done to check manufacturing variability.
2. The element with the higher pressure drop was selected for the remaining test sequences. The lower pressure drop unit will be shipped to the customer.
3. The system was then set to the maximum flow rate that could be achieved from the current test facility and the pressure drop across the Turbodyne system recorded (keeping the air temperature as close to 375°F as possible).
4. The flow rate is subsequently reduced to 1.5 lb/sec while keeping the air temperature at 375°F and pressure at 33 PSIA.

At each of the above conditions, the flow was established for 30 minutes for the system to stabilize before recording data. This testing is to provide the system impedance characteristics which will be used to predict pressure losses at actual design flow temperature and pressure conditions.

4.0 TESTING - cont'd

Test B

1. The system was next set to the 60% rated flow conditions and run for 24 hours. At the end of this test, it was powered down for 8 hours and then re-run for an additional 24 hours while measuring all pressure/temperature parameters as outlined earlier. This testing will evaluate the system for any thermal expansion and contraction related problems.

Test C

1. With the system set at 60% rated flow conditions, SAE Fine test dust at the rate of 2 gms/min (2.5 x "0" visibility) was fed for a duration of 24 hours. This dust feed rate is equivalent to the effluent from a two stage 98% inertial separator.
2. The Turbodyne system is next run for 8 hours with no dust feed. This is performed to check the stabilized clean ΔP .

Test D

This testing was conducted to evaluate the system at a dust feed rate of "0" x visibility. The previous testing with 2.5 x "0" visibility was considered excessive. Also evaluated during this testing was the effect of higher system pressure during blowback cycle and its effect on stabilized system pressure drop. The "0" x visibility testing at 60% rated condition is conducted for two 24 hour durations with an intermittent 4 hour testing with no dust ingestion.

Test E

At the conclusion of above testing, the system was disassembled and inspected for any dust tracking or leakage. Overall system efficiency was also measured using Isokinetic probes located upstream and downstream of the Turbodyne unit.

5.0 TEST RESULTS

Test A

The two fabricated elements were tested for pressure drop at 1662 SCFM (1.98 lb/sec) to check for any manufacturing variations. The pressure pick-up points are as located on the air cleaner system which are to be subsequently used to monitor element ΔP through a pressure transducer. At this flow, element 1 had a ΔP of 8.8" H₂O and element 2 had a ΔP of 8.0" H₂O. The scan conducted on the higher ΔP element is as shown:

FLOW SCFM	INLET TEMP. °F	INLET PRESSURE PSIG	ΔP IN H ₂ O
1202	376.2	19.2	6.0
1578	377.4	18.8	8.2
1617	378.7	19.1	8.4
1662	377.3	20.0	8.8

Graph of ΔP v/s flow for this element is as shown in Figure 2.

Test B

Two 24 hour tests as planned, were successfully completed. These tests were conducted at 60% of rated flow conditions. No abnormalities in ΔP or in system rotational or blowback mechanisms were observed. The testing to this point has been conducted with no dust and has proven the system rotational and blowback reliability.

ΔP V/S FLOW THROUGH TURBODYNE SYSTEM

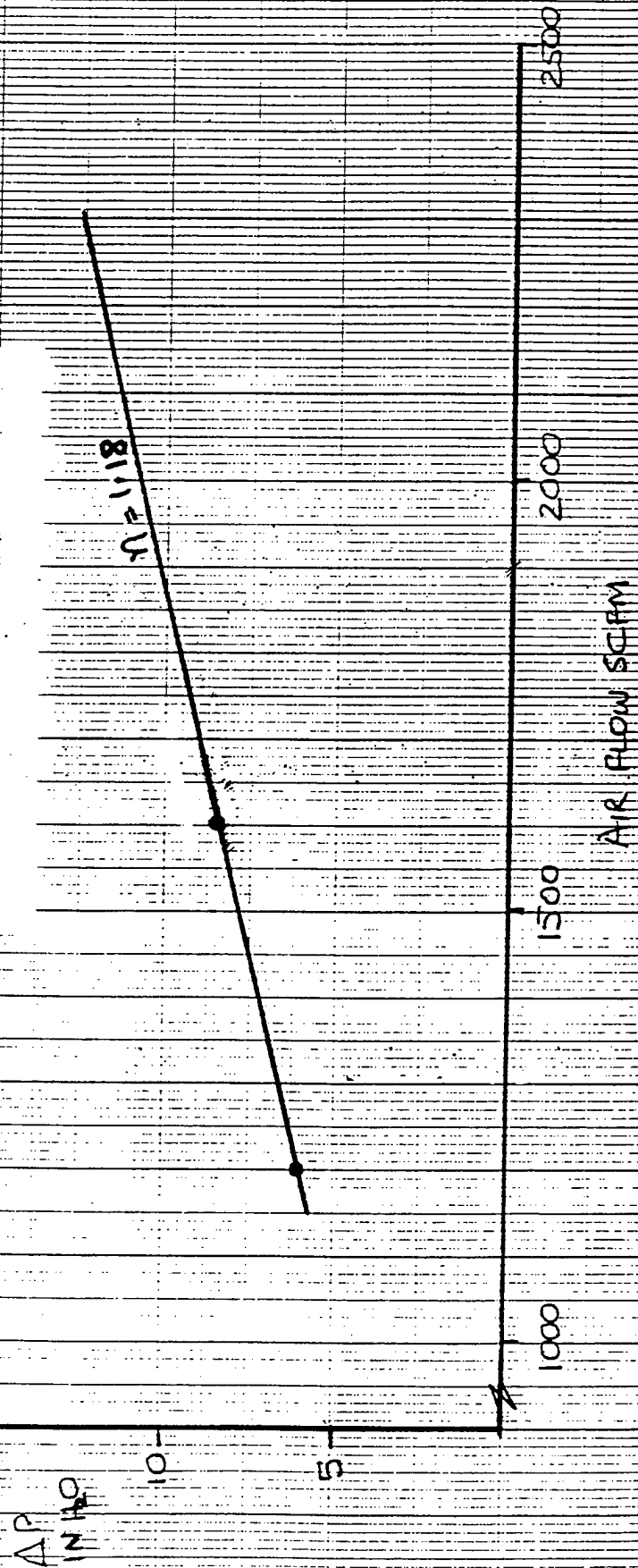
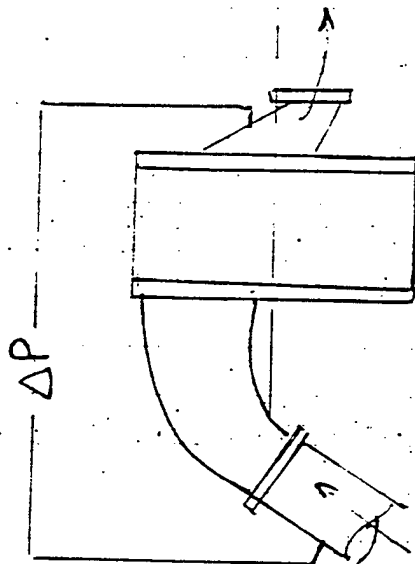


FIG 2

5.0 TEST RESULTS - cont'd

Test C

Element 1 was selected to be used for the dust evaluation. Dust (SAE Fine) at the rate of 2 gms/min was fed into the Turbodyne system while the flow conditions were established to 60% rated. The pressure drop measured across the element for a duration of 24 hours is as follows:

TIME (HRS)	ΔP
0	0.3 PSID
6	1.68 PSID
12	2.19 PSID
18	2.58 PSID
24	3.0 PSID

After an 8 hour clean-up cycle, the element ΔP was recorded at 1.74 PSID. The ΔP stabilized to this final value within the first hour of the clean-up cycle.

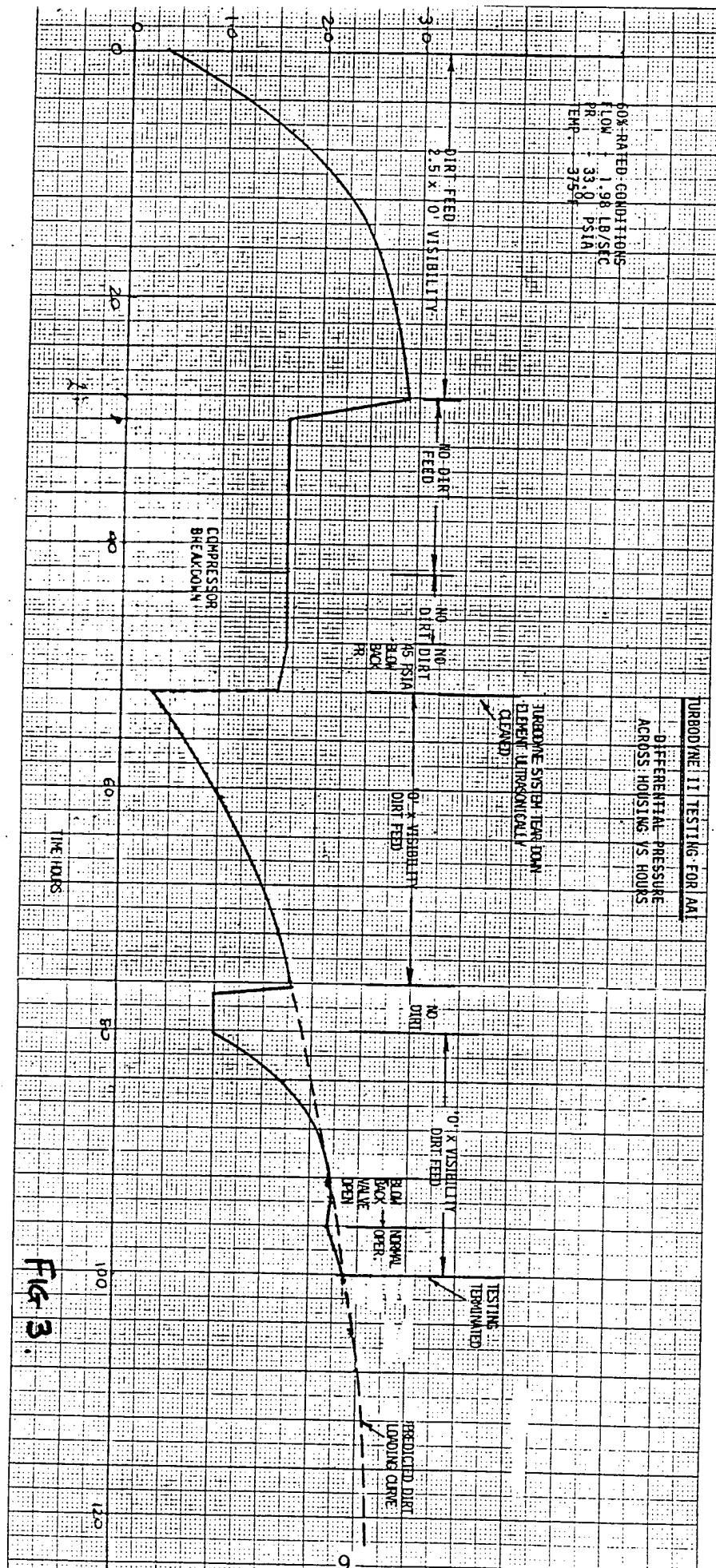
Test D

Test D was conducted with the element ultrasonically cleaned and reassembled in the housing. The cleaned ΔP matched closely to the ΔP of the brand new element. The two 24 hours "0"x Visibility equipment tests (48grms/hr SAE Fine into the element) with an intermediate four hour no dirt feed cycle were successfully completed. During the second dirt feed cycle, the solenoid valve was observed to remain open for a duration of about 4 hours. The element during these 4 hours was being continuously cleaned. A gentle tapping on the side of the valve body enabled it to function normally and the test completed. The testing was stopped 4 hours short in this cycle due to a system (hot-gas facility) malfunction.

The ΔP vs. time results for test C and D is as per attached graph (Fig. 3) which shows a predicted system (Turbodyne element and housing) ΔP of approximately 2.75-2.8 PSID as a stabilized value approaching the 200 hour of operation.

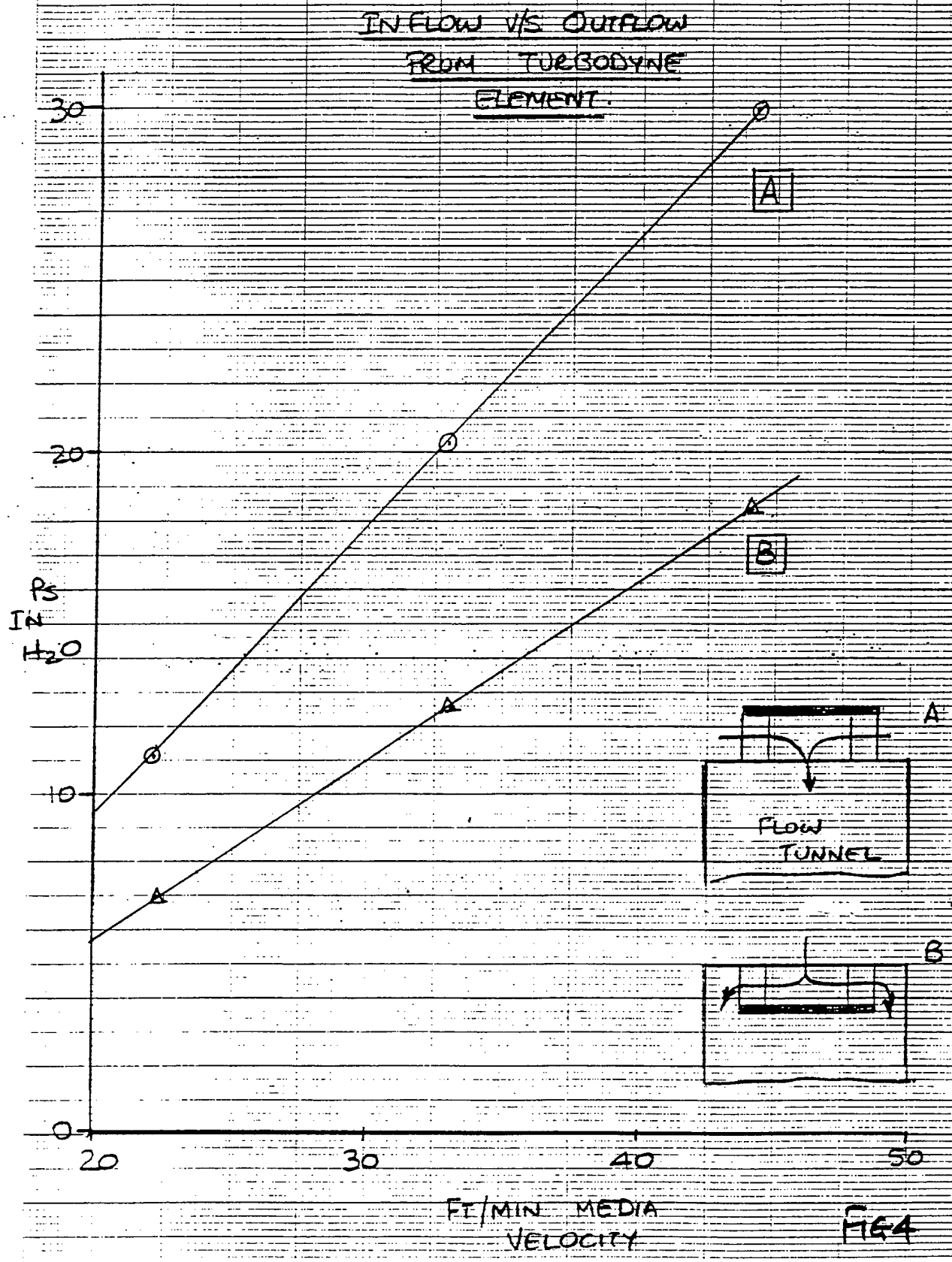
Test E

The filter assembly was disassembled and visually examined. No signs of dirt tracking or leakage was observed. Overall system efficiency could not be conclusively measured and is not reported.



6.0 CONCLUSION

1. After subjecting the Turbodyne system to elevated temperatures and pressures for approximately 150 hours. The new rotational and blowback mechanism design has proven to be quite successful. This design will be further improved as additional units are fabricated.
2. At the 60% rated flow the stabilized ΔP was expected to be about 2 PSID. The value reached here is 2.75 PSIA. Two factors in the design are believed to be contributing to this higher than expected ΔP rise. From Figure 3, it is observed that even when the system pressure is increased to 45 PSIA no additional cleaning was observed. This suggests that the higher blowback velocities is not effectively cleaning the element. Detailed examination of the element pleat geometry concluded that the pleat spacing at the inner diameter is very restrictive and is locally choking the blowback flow. The normal chock-off point in the blowback path is at the solenoid valve. Further evidence of this tighter pleat geometry is observed from Figure 4, which shows a considerable difference in pressure drop between outflow v/s inflow out of the element when tested on the wind tunnel. The current design is 7.0 pleats per inch (PPI) on the inner diameter and can be reduced to 5.5 PPI without significantly increasing the clean pressure drop. However, this open geometry design would provide an effective cleaning during blowback cycle and hence, a lower stabilized ΔP .



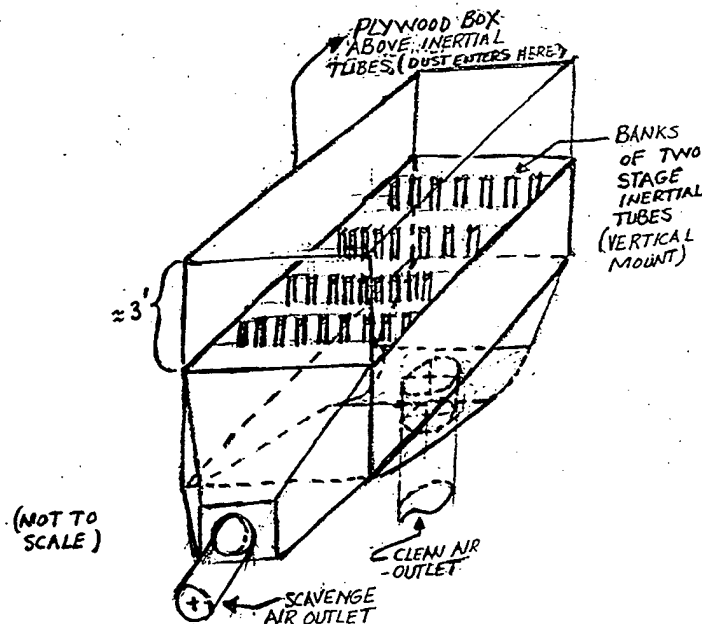
APPENDIX F

TEST PLAN FOR TURBODYNE II PRECLEANER (TDIIPC)

TEST PLAN FOR TURBODYNE II PRECLEANER (TDIIPC)

A. TURBODYNE II PRECLEANER TEST SET-UP (CONFIG. 1)

1. THE TDIIPC WILL BE SET-UP IN BLDG. 7 OPEN BAY AREA WITH TWO STAGE PRECLEANER TUBES IN VERTICAL FLOW POSITION. THIS POSITIONS CLEAN AIR OUTLET DUCT ALSO IN VERTICAL FLOW MODE REQUIRING A TALL TEST DUST FEED SET-UP. ABOVE THE TDIIPC INLET CONSTRUCT A PLYWOOD BOX APPROXIMATELY 3 FOOT IN HEIGHT. DUST WILL BE FED IN THE TOP OPENING OF PLYWOOD BOX. AS WITH OTHER TYPICAL AIR CLEANER TESTS, THERE WILL BE A SCAVENGING DUCT TUBE WHICH WILL DUMP INTO A AIR CLEANER HOUSING WITH FILTER (TYPICALLY 5 TON TRUCK AIR CLEANER). THE DUCT WILL THEN CONTINUE TO AN ORFICE SET-UP TO MEASURE AIR FLOW AND THEN TO A BLOWER MOTOR WHICH PROVIDES THE FLOW. JUST OUTSIDE THE SCAVENGING DUCT OF TDIIPC WILL BE A SCAVENGING BLOWER MOTOR FOR THE FIRST SERIES OF TESTS. THIS SCAVENGING BLOWER MOTOR (SBM) RUNS AT A CONSTANT SPEED. THERE WILL BE NO RESTRICTION ON THE INLET SIDE OF SBM SINCE IT IS POSITIONED CLOSE TO TDIIPC SCAVENGE OUTLET DUCT. ON THE OUTLET DUCT DOWNSTREAM OF OF SBM IS A RESTRICTION TAP WHICH WE CAN CONTROL THE OUTLET RESTRICTION BASED ON THE BLDG.7 SCAVENGE BLOWER MOTOR SETTING. THE CLEAN AIR OTLET OF TDIIPC WILL HAVE A RESTRICTION TAP JUST OUTSIDE THE DUCT AND WILL THEN FLOW TO A BARRIER FILTER AND A MASTER FILTER. THIS MAIN CLEAN AIRFLOW IS CONTROLLED BY A LARGE BLOWER SYSTEM WHICH CAN REGULATE AND MEASURED THRU AN ORFICE THE DESIRED AIRFLOW TEST POINTS.



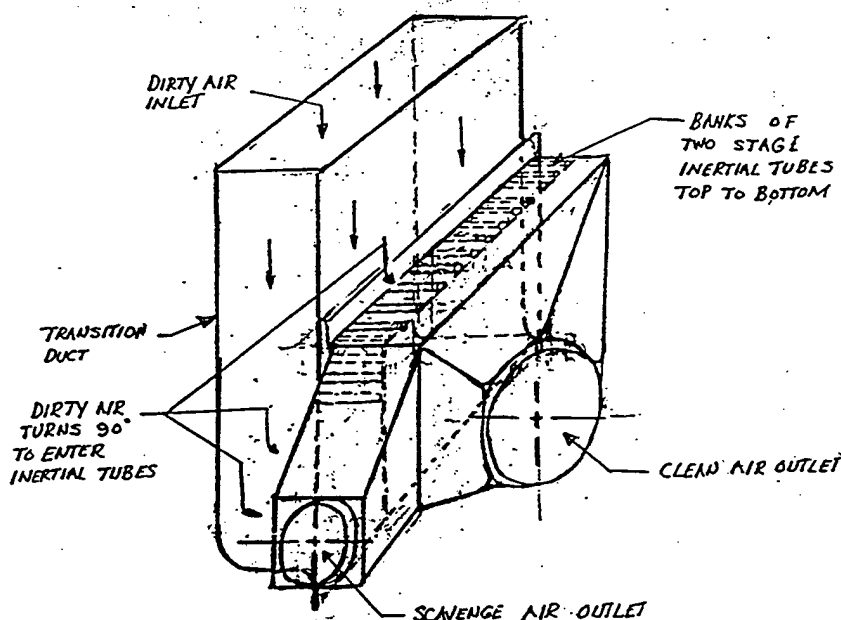
CONFIG. 1

2. CONFIGURATION 1 TESTS WITHOUT SCM INSTALLED. REMOVE THE SBM AND INSTALL A STRAIGHT DUCT TUBE IN IT'S PLACE. THIS WILL ALLOW US TO CONDUCT TESTS AT VARIABLE SCAVENGE FLOW RATES TO OBTAIN A COMPARISON WITH PREVIOUSLY CONDUCTED FOREIGN AIR CLEANERS WHICH WERE INERTIAL TUBE DESIGNS WITHOUT BARRIER FILTERS. THE SCAVENGE FLOW RATES WILL BE CONDUCTED AT 10, 15, 20 AND 25 PERCENT OF THE CLEAN AIR FLOW AND AT A CONSTANT DUST DENSITY OF $.0227 \text{ G/FT}^3$.

B. TURBODYNE II PRECLEANER TEST SET-UP (CONFIG. 2)

1. IF TIME AND FUNDS PERMIT, THE TDIIPC WILL BE SET-UP WITH INERTIAL TUBES MOUNTED IN HORIZONTAL PLANE. THIS WILL REQUIRE THAT A CURVED SHAPED TRANSITION DUCT BE FABRICATED. THE TEST DUST WILL STILL BE FED IN FROM THE TOP. THIS WILL DETERMINE IF ANY PERFORMANCE DEGRADATION OCCURS WHEN GOING FROM A VERTICAL TO A HORIZONTAL PLANE. TESTS AS CONDUCTED IN CONFIGURATION 1 WILL BE CONDUCTED.

2. A SKETCH OF THE ORIENTATION IS AS FOLLOWS:



CONFIG. 2

C. TURBODYNE II PRECLEANER TESTING PARAMETERS (CONFIG. 1 & 2)

1. DUST FEED RATE WILL BE BASED ON CLEAN SIDE AIRFLOW.
2. RATED CLEAN AIR FLOW TO ENGINE IS 2640 CFM, ROUND TO 2600

CFM, BASED ON NOMINAL 20 PERCENT SCAVENGING FOR TDIIPC, THE AIR FLOW TO TDIIPC INLET WOULD BE 3130 CFM, INCLUDES 10 CFM FOR BARRIER FILTER SCAVENGE AIR FLOW.

3. AIR FLOW RANGE CONSISTS OF 5 TEST POINTS BETWEEN ENGINE IDLE AIRFLOW AND ENGINE RATED AIR FLOW. CLEAN AIR FLOW OUT OF TDIIPC WOULD BE 600, 1100, 1600, 2100 AND 2600 CFM. AT 20 PERCENT SCAVENGING AIR FLOW THE AIR FLOW TEST POINTS ENTERING TDIIPC WOULD BE 730, 1330, 1930, 2530 AND 3130 CFM.

4. TEST DURATION WILL BE TO M1 PRECLEANER SPECIFICATION (30 MINUTES) AND WILL BE RAN BOTH ON FINE AND COARSE TEST DUST. THE TEST DUST USED WILL BE PTI AND AC. TEMPERATURE AND HUMIDITY REQUIREMENTS WILL BE PER M1 PRECLEANER SPECIFICATION. THE TEMPERATURE IS $80 \pm 10^{\circ}\text{F}$ AND A RELATIVE HUMIDITY OF 50 ± 30 PERCENT.

5. A TERM "DUST DENSITY" WILL BE DEFINED AT A NOMINAL 10 PERCENT SCAVENGING FLOW RATE AND THE GRAMS AND FEED RATE CALCULATED FOR EACH TEST. FOR EXAMPLE AT 2600 CFM CLEAN AIR FLOW 65 GRAMS/MINUTE WILL BE FEED. THIS IS CALCULATED FROM TAKING DUST FEED RATE AT ZERO DUST VISIBILITY (.025 GRAMS PER CUBIC FOOT) AND MULTIPLYING BY 2600 CFM. AT 10 PERCENT SCAVENGING (260 CFM) THE ACTUAL DUST VISIBILITY RATE INTO THE TDIIPC WOULD^b $.0227 \text{ GRAMS/FT}^3$. THIS IS CALCULATED BY TAKING 65 GRAMS/MINUTE AND DIVIDING BY 2860 CFM. FOR ALL TESTS WE WOULD LIKE TO MAINTAIN THIS SAME DUST DENSITY OF $.0227 \text{ GRAMS/FT}^3$, THUS THE DUST FEED RATE IN GRAMS/MINUTE WILL CHANGE FOR EACH AIR FLOW TEST POINT AND FOR EACH CHANGE IN SCAVENGING FLOW.

D. PALL'S SCAVENGE BLOWER MOTOR PERFOR. CHARACTER TEST (CONFIG. 1)

1. MAPPING CHARACTERISTICS (NO DUST FEED)

INSTALL PALL'S SCAVENGE BLOWER MOTOR (SBM) CLOSE TO TDIIPC SCAVENGING OUTLET. THE MAPPING OF TDIIPC WITH SBM INSTALLED WILL BE CONDUCTED WITHOUT FEEDING TEST DUST. THE FIVE CLEAN AIR FLOW TEST POINTS ARE 600, 1100, 1600, 2100 AND 2600 CFM. THESE CFM'S WOULD BE THE AIRFLOW EXITING THE TDIIPC ON WAY TO ENGINE INLET OR IN CASE OF TURBODYNE II DESIGN, THE STAINLESS STEEL BARRIER FILTER AHEAD OF ENGINE INLET. AT EACH CFM TEST POINT WE WILL ALSO RUN A MINIMUM OF 5 ADDITIONAL TEST POINTS WITH INCREASING RESTRICTION ON THE SBM OUTLET UNTIL THE SBM STALLS. THIS WILL BE VERIFIED BY A LOSS IN SCAVENGING FLOW AND INCREASE IN SBM SPEED. THE INITIAL TEST POINT FOR EACH CFM CLEAN AIR OUTLET WILL BE RUN AT ZERO RESTRICTION (ATMOSPHERIC) ON THE SBM. THESE TESTS WILL ALSO MEASURE AND RECORD THE SCAVENGING CFM'S PRODUCED BY SBM FOR EACH CFM TEST POINT. FOR EXAMPLE IF AT 2600 CFM CLEAN AIR FLOW THE SBM PRODUCES A 20 TO 22 PERCENT SCAVENGING FLOW (520 TO 572 CFM), THIS WOULD RELATE TO A NEARLY 100 PERCENT SCAVENGE FLOW AT THE 600 CFM CLEAN AIR OUTLET TEST POINT. SCAVENGING FLOW NUMBERS SHOULD REDUCE AS RESTRICTION IS PLACED ON THE SBM WHICH WILL BE VERIFIED BY THIS MAPPING. IF TIME PERMITS IT WOULD BE DESIRABLE TO CREATE SOME RESTRICTION AHEAD OF SBM. FOR EXAMPLE THIS COULD

BE A FLEXIBLE TUBE 5 FEET IN LENGTH FROM THE TDIIPC SCAVENGE OUTLET AND AHEAD OF SBM. THIS WOULD SIMULATE A TYPICAL SET-UP THAT IS USED IN THE M1A1 TANK PERCLELANER SCAVENGING DESIGN. A FEW COMPARSION TESTS WOULD MAP THE SCAVENGE FLOW REDUCTION CAUSED BY THE RESTRICTION.

2. TDIIPC AIRFLOW RESTRICTION TEST

DURING THE FIRST SERIES OF MAPPING TESTS WITH ZERO RESTRICTION PLACED ON SBM, CONDUCT AN AIR FLOW RESTRICTION TEST. IN ADDITION TO 600, 1100, 1600, 2100, AND 2600 CLEAN AIR FLOW TEST POINTS, CONDUCT RESTRICTIONS AT AIR FLOWS OF 3100 AND 3600 CFM CLEAN AIR FLOW. THE 3600 CFM TEST POINT WILL BE APROXIMATELY 140 PERCENT ABOVE THE 2600 CFM RATED ENGINE AIR FLOW TEST POINT. THIS NEARLY COMPLIES WITH SAE'S AIR CLEANERS TEST CODE AIR FLOW MAX RANGE OF 150 PERCENT ABOVE RATED AIR FLOW.

3. TDIIPC DUST FEED EFFICIENCY TESTS WITH SBM INSTALLED

a. CONDUCT DUST TESTS AND MEASURE EFFICIENCY OF TDIIPC USING BOTH PTI FINE AND COARSE TEST DUST. THE TEST DUST CONCENTRATION IN GRAMS PER CUBIC FEET WILL BE ESTABLISHED THROUGH A CONSTANT "DUST DENSITY" VALUE OF .0227 GRAMS PER CUBIC FOOT. THE GRAMS PER MINUTE TO BE FEED FOR EACH AIR FLOW TEST POINT WILL BE CALCULATED FROM THE CONSTANT DUST DENSITY OF .0227 GRAMS PER CUBIC FOOT REGARDLESS OF THE SCAVENGE FLOW RATE. FOR EXAMPLE AT THE 2600 CFM CLEAM AIR TEST POINT THE DUST FEED RATE IS EQUAL TO 65 GRAMS PER MINUTE AT A 10 PERCENT SCAVENGING FLOW RATE. THE RELATIONSHIP BETWEEN ZERO DUST VISIBILITY (.025 GRAMS PER CUBIC FOOT) AND THE CONSTANT DUST DENSITY OF .0227 GRAMS PER CUBIC FOOT IS THAT ZERO DUST VISIBILITY IS BASED ON THE CLEAN AIR FLOW WHEREAS THE DUST DENSITY CONSTANT OF .0227 GRAMS PER CUBIC FOOT IS BASED ON A 10 PERCENT SCAVENGING FLOW AND DUST CONCENTATION ACTUALLY BEING FEED INTO THE PRECLEANER INLET. A 10 PERCENT SCAVENGING FLOW OF 2600 CFM CLEAN AIR FLOW IS 260 CFM PLUS 2600 CFM CLEAN AIR ADDS TO A 2860 CFM INTO THE TDIIPC. THUS, 65 GRAMS PER MINUTE DIVIDED BY 2860 CFM GIVES A .0227 GRAMS PER CUBIC FOOT VALUE WHICH WE CHOOSE TO CALL THE CONSTANT DUST DENSITY VALUE. FOR OTHER AIR FLOW TEST POINTS AT 10 PERCENT SCAVENGING ALL THAT CHANGES IS THE DUST FEED RATE. FOR EXAMPLE AT 2100 CFM CLEAN AIR OUTLET AT ZERO DUST VISIBILTY (.025 GRAMS PER CUBIC FOOT) WE GET 52.5 GRAMS PER MINUTE AS THE FEED RATE. WHEN DIVIDING 52.5 BY THE CLEAN AIR FLOW RATE OF 2100 CFM PLUS THE SCAVENGING FLOW RATE OF 210 CFM WE GET .0227 GRAMS PER CUBIC FOOT WHICH IS AGAIN THE CONSTANT DUST DENSITY. HOWEVER, WHEN WE CHANGE THE SCAVENGING FLOW RATE FROM SAY 10 PERCENT TO 20 PERCENT OR ANY OTHER NUMBER THAN 10 PERCENT WE GET A DIFFERENT FEED RATE. FOR EXAMPLE AT 20 PERCENT SCAVENGE AND 2600 CFM CLEAN AIR FLOW WHILE MAINTAINING A CONSTANT DUST DENSITY OF .0227 GRAMS PER CUBIC FOOT, WE GET A FEED RATE OF 70.9 GRAMS PER MINUTE. THIS IS OBTAINED BY MULTIPYING .0227 GRAMS PER CUBIC FOOT BY 3120 CFM (2600 CFM PLUS 20 PERCENT OF 2600 IS 520 CFM). THIS EXPLANATION WILL BE USED FOR ALL SCAVENGING FLOW RATES DIFFERENT THAN 10 % AND FOR SCAVENGING FLOW RATES THAT MAY APPROACH 100 % WHEN USING SBM AT ENGINE IDLE AIR FLOW OF 600 CFM.

CONDUCT PTI FINE AND COARSE DUST EFFICIENCY TESTS AT CLEAN AIR FLOW RATES OF 600, 1100, 1600, 2100 AND 2600 CFM. THE SCAVENGING FLOW RATES PRODUCED BY SBM WILL BE BASED ON TEST DATA OBTAINED DURING MAPPING CHARACTERISTICS. (PARAGRAPH D.1.)

b. REPEAT THESE SAME TESTS POINTS ABOVE, HOWEVER USE AC FINE AND COARSE TEST DUST.

c. REPEAT ONE TEST POINT AT HIGH DUST FEED RATE OF 5 TIMES 0 DUST VISIBILITY. THIS CAN BE DONE ON PTI TEST DUST AND EITHER FINE OR COARSE. (IF TIME PERMITS)

4. TDIIPC DUST FEED EFFICIENCY TESTS WITH SBM REMOVED

a. THESE SERIES OF TESTS WILL BE CONDUCTED WITH THE SBM REMOVED WHICH WILL ALLOW US TO CONTROL THE SCAVENGING FLOW RATE. THIS WILL ALLOW US TO DIRECTLY COMPARE THE TDIIPC WITH PREVIOUSLY RAN FOREIGN AIR CLEANERS WHICH HAD NO BARRIER FILTER AND WERE AIR CLEANERS DESIGNED AS A PRECLEANER. THEY HAD BEEN TESTED AT SCAVENGING FLOW RATES OF 5, 10 AND 15. THE SAME AIR FLOW TEST POINTS WILL BE USED AND SCAVENGING FLOW RATES OF 10 AND 15 PERCENT WILL BE CONDUCTED FIRST. THESE TESTS WILL BE CONDUCTED ON PTI FINE AND COARSE TEST DUST. IF TIME PERMITS CONDUCT FOLLOW ON TESTS AT 20 AND 25 PERCENT SCAVENGING AIR FLOWS. THIS WILL PROVIDE A COMPARIOSN OF EFFICIENCIES WITH AND WITHOUT SBM INSTALLED.

b. CONDUCT ONE TEST POINT AT HIGH DUST FEED RATE OF 5 TIMES 0 DUST VISIBILITY ON BOTH FINE AND COARSE TEST DUST.

5. TDIIPC DUST FEED EFFICIENCY TESTS WITH SBM INSTALLED (CONFIG. 2)

CONDUCT TESTS IN PARAGRAPH D.2.3.a WITH TDIIPC INSTALLED AS IN CONFIGURATION 2. AND SBM INSTALLED.

6. TDIIPC DUST FEED EFFICIENCY TESTS WITH SBM REMOVED (CONFIG. 2)

CONDUCT TESTS IN PARAGRAPH D.4.a. WITH TDIIPC INSTALLED AS IN CONFIGURATION 2. BUT WITH SBM REMOVED.

E. TDIIPC DUST EFFICIENCY TEST WITH RESTR. ON SBM INLET/OUTLET

CONNECT A FLEXIBLE HOSE TO SBM INLET (SIMILAR TO M1A1 TANK INSTALLATION, EX. 5 FEET IN LENGTH). CONDUCT DUST TEST WITH PTI COARSE TEST DUST AND A RESTRICTION ON SBM OUTLET (EX 5 TO 10 INCHES OF WATER). THE 5 CLEAN AIR FLOW TEST POINTS WILL BE USED.

APPENDIX G

CRUSADER TYPE TURBODYNE II PRECLEANER
PARTICLE SIZE DETERMINATION

CRUSADER TURBODYNE II PRECLEANER PARTICLE SIZE DETERMINATION

FINAL REPORT

**SwRI Project No. 03-8499
Contract No. DAAE07-95-C-R081; PS0004**

Prepared for:

**U.S. Army Tank - Automotive & Armaments Command
Research, Development & Engineering Center
Attn: AMSTA-TR-R
Warren, MI 48397-5000**

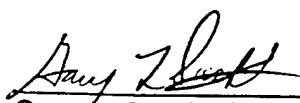
Prepared by:

Martin B. Treuhaft

**Southwest Research Institute
Vehicle Systems Research Department
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April, 1998

Approved:



**Gary L. Stecklein, Director
Vehicle Systems Research Department**

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EXECUTIVE SUMMARY

This report presents results of laboratory testing, conducted on a Crusader Turbodyne II Precleaner, which measured gravimetric efficiencies directly as a function of airflow and inlet dust concentration, and fractional efficiencies indirectly, derived from calculations based on measurements of downstream particle size distributions. Testing, using PTI SAE Coarse test dust, was conducted over a downstream airflow range of 600 to 2,600 cfm, with constant scavenge of 520 cfm, for dust concentration of 0.025 (zero dust visibility), 0.0125, and 0.00625 grams per cubic foot air.

Downstream particle sizing was accomplished for particles ranging in size from 0.5 to 20 μm using an optical particle counter which is known to respond well to non-spherical, polydispersed, natural dusts similar to the tests dust used in this project. These measurements were used to develop downstream particle size distributions and to characterize precleaner removal performance as a function of geometric, and by inference, Stokes and aerodynamic particle size.

The downstream mass distributions were very nearly log-normal, having a mass median geometric diameter for all test conditions of about 5 to 6 μm . Cumulative efficiency predicted by particle sizing was in reasonable agreement with measured gravimetric values. Fractional efficiencies calculated from corresponding upstream and downstream concentration levels and particle size ranges showed effective geometric cut sizes ranging from 3 to 6.5 μm , for all cases tested.

Test results are presented in graphical and tabular form, and discussed analytically.

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1.0 INTRODUCTION

This report presents results of airflow resistance, gravimetric, and fractional efficiency testing, and the measurement of downstream particle size distributions for a Crusader Turbodyne II Precleaner (Centrisep CE 00852-1d9; s/n A001) provided by the U.S. Army Tank-Automotive and Armaments Command (TACOM/TARDEC) for evaluation under Work Directive PS0004 of the Propulsion System Technology Support Contract DAAE07-95-C-R081. Airflow resistance was determined by measuring pressure drop across the unit, at constant scavenge flow (520 scfm; 20 percent of rated flow), as a function of primary air flow over the range of 600 to 2,600 scfm (28.7 C; 101.3 kPa). Gravimetric efficiency was measured by comparing the dust captured by a downstream absolute filter in relation to the dust fed, using conventional Mil-Spec and SAE J726 techniques. Fractional efficiencies were determined by measuring downstream particle size distributions over a series of particle size ranges, calculating downstream mass assuming spherical particles, and comparing the results to upstream mass as calculated from the dust feed rate during testing and the particle size distribution data provided with the test dust. Gravimetric measurement and particle sizing were accomplished simultaneously for each test run at nominal dust concentrations representing zero dust visibility (0.025 g/ft³ air), and half and quarter zero dust visibility. Several replicates were run at each airflow rate to provide better statistics.

Downstream particle counting was accomplished in six (6) specific size ranges spanning an overall range of 0.5 to 20 μ m. Particle counting was accomplished using a HIAC/Royco 4102 particle sizing analyzer consisting of a 4,100 counter and a 1,200 white light sensor. These instruments were calibrated prior to testing. This unit, which measures physical (geometric) size based on the particle's light scattering characteristics, is known to respond well to non-spherical, polydispersed, natural dusts and has shown good sensitivity to the SAE type dust used in this project. Multiple downstream isokinetic samples were taken during each test so that systematic perturbations could be minimized by averaging results from repetitive measurements.

2.0 EXPERIMENTAL ARRANGEMENT

The experimental arrangement with respect to the air flows into and out of the precleaner is shown schematically in Figure 1. Specific air flow rates used during testing are listed in Table 1. The overall test arrangement is shown photographically in Figures 2 and 3. In particular, Figure 2a shows the rectangular inlet, the clear 8-inch id downstream piezometer and sampling tube, the transition duct (foreground) leading to the absolute filter, and the scavenge duct (background) leading to the secondary flow system. Figure 2b shows the 8-in schedule 40 PVC transition ducting and the absolute filter holder, while Figure 2c shows the inlet, the outlet peizometer and sampling tube, and the 6-in schedule 40 PVC scavenge duct. Figure 3 shows the particle size measurement system, including the HIAC/ROYCO 4,100 particle counter and 1,200 sensor, and the downstream piezometer tube and isokinetic probe. Prior to testing, orthogonal airflow velocity measurements were made across the tube, at each airflow, to confirm the presence of well developed, turbulent velocity profiles in the sampling area. Lateral measurements to seek evidence of rotational swirl were not accomplished or considered necessary. Individual sampling probes, designed to provide isokinetic entrance conditions, were designed and fabricated for each air flow.

Two heavy-duty SAE dust injectors (Ref SAE J726 JUN93, Fig 16), one per injection system, were used to feed dust into the inlet in a manner to maximize spacial dispersion. PTI SAE Coarse Test Dust, Batch 4716C, was used for all testing. The manufacture's particle size data for this dust is given in the Appendix. The mass distribution derived from these data was used to define upstream incremental mass levels for calculating fractional efficiency in each particle size range, as discussed later.

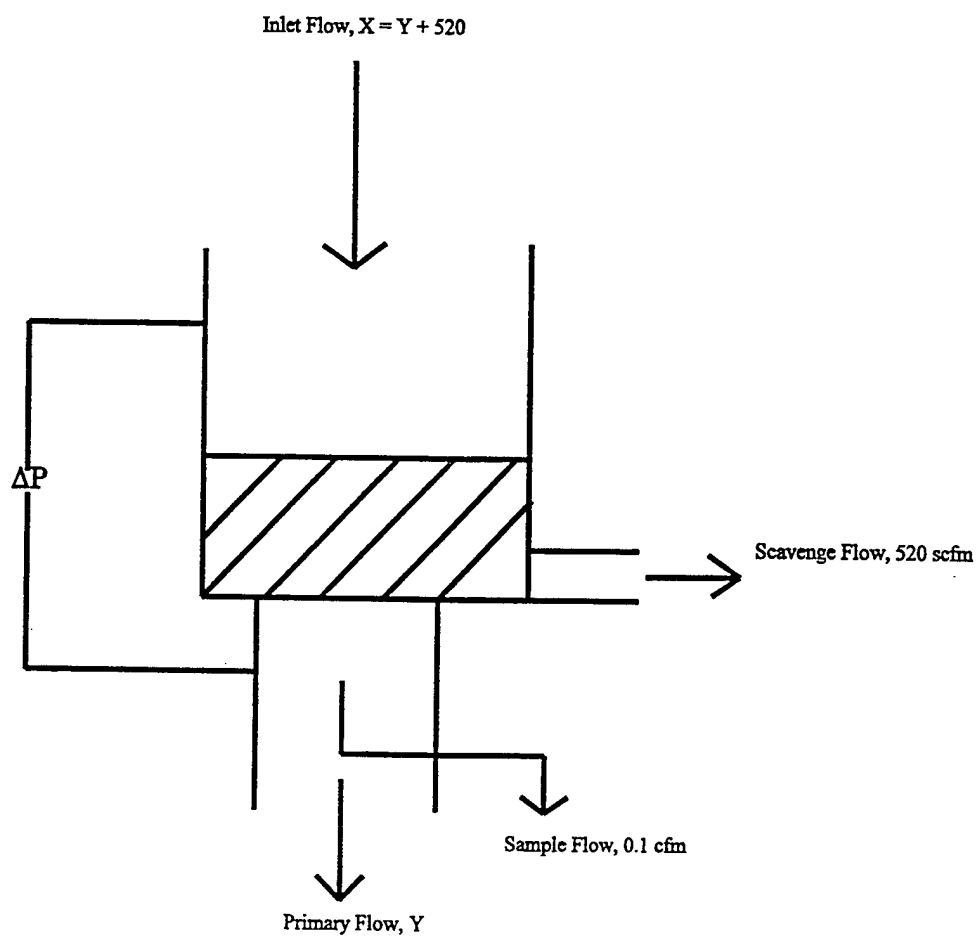
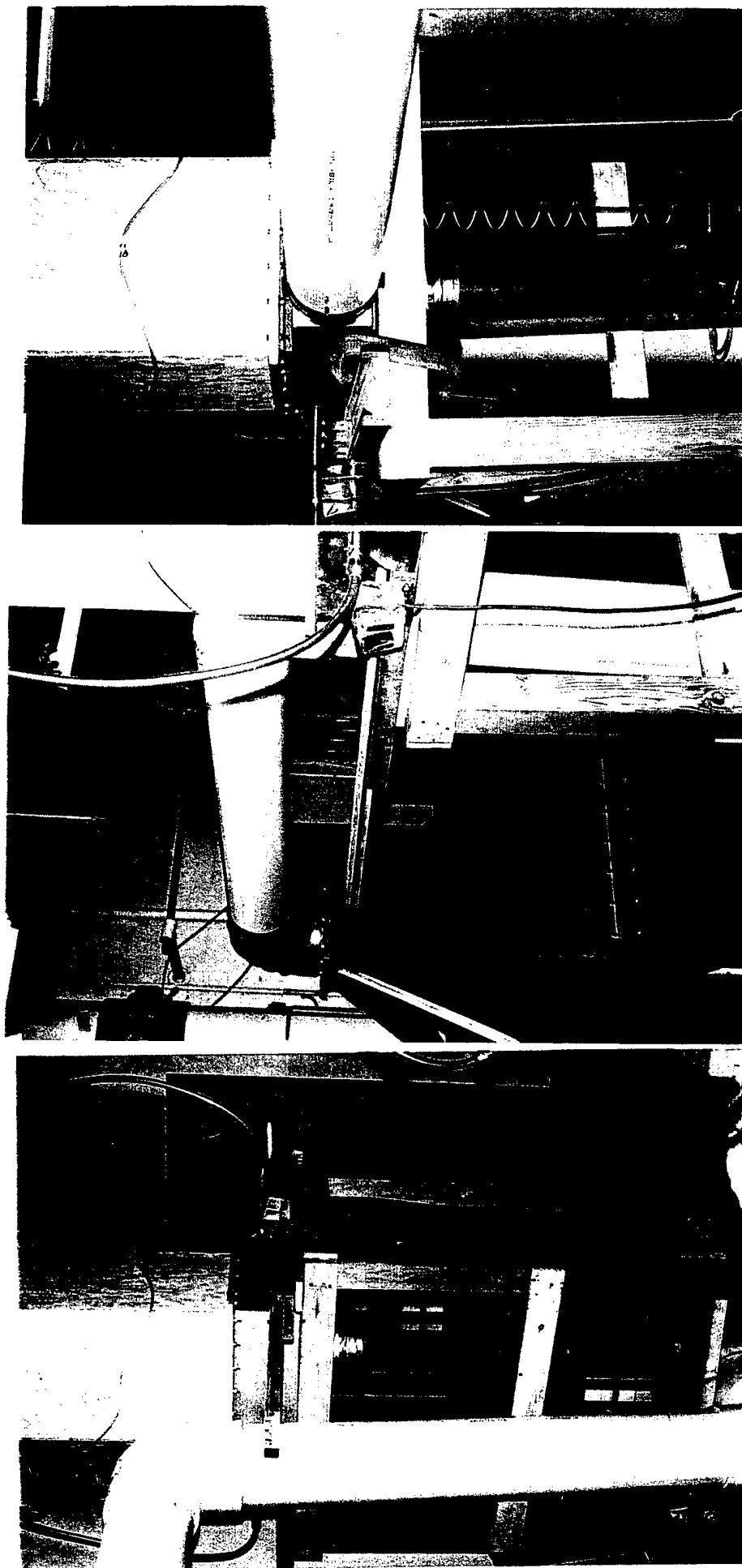


FIGURE 1. SCHEMATIC REPRESENTATION OF PRECLEANER AIRFLOWS DURING TESTING

TABLE 1. CRUSADER TURBODYNE II PRECLEANER TEST CONDITIONS AND RESULTS (Scavenge Air Flow = 520 scfm for All Tests)

Test No.	Primary Air Flow, cfm	Inlet Air Flow, cfm	ΔP , inches of water	Dust fed, g/20 min	Upstream Dust Conc; g/ft ³ air	Gravimetric Efficiency, %	By Particle Counting, %
1	2600	3120	11.1	1554.2	0.02491	98.427	97.507
2	2600	3120	11.0	1556.8	0.02495	98.454	97.507
3	2600	3120	11.2	780.9	0.01251	98.442	95.444
4	2100	2620	7.7	1309.2	0.02498	98.836	98.423
5	2100	2620	7.7	655.0	0.01250	98.774	96.368
6	2100	2620	7.7	1306.5	0.02493	98.765	N/A
7	1600	2120	4.7	1058.8	0.02497	98.709	98.038
8	1600	2120	4.7	1054.7	0.02488	98.688	N/A
9	1600	2120	4.7	529.4	0.01246	98.578	95.778
10	1100	1620	2.6	808.6	0.02496	98.732	N/A
11	1100	1620	2.6	810.4	0.02501	98.739	N/A
12	1100	1620	2.6	405.4	0.01251	98.590	95.827
13	600	1120	1.1	560.8	0.02500	98.502	N/A
14	600	1120	1.1	558.9	0.02495	98.524	N/A
15	600	1120	1.2	281.1	0.01255	98.527	94.773
16	600	1120	1.2	139.5	0.00623	98.652	94.703
17	1100	1620	2.7	202.0	0.00624	98.322	94.247
18	1600	2120	4.9	267.1	0.00630	97.495	95.313
19	2100	2620	8.1	656.1	0.01252	96.106	96.502
20	2600	3120	11.2	780.8	0.01251	96.240	95.148
21	2600	3120	11.0	779.5	0.01249	97.780	96.645



C

B

A

FIGURE 2. EXPERIMENTAL ARRANGEMENT FOR TESTING TURBODRYNE II PRECLEANER
TO DETERMINE OPERATING EFFICIENCY AND DOWNSTREAM PARTICLE SIZE DISTRIBUTIONS

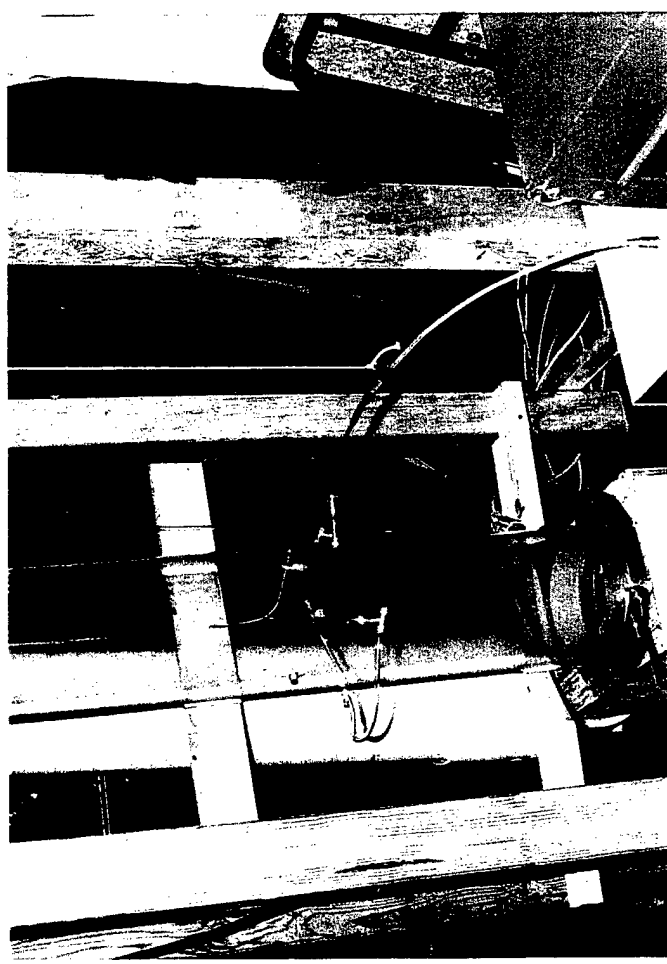


FIGURE 3. PARTICLE SIZE MEASUREMENTS SYSTEM: HIAC/ROYCO 4100 PARTICLE COUNTER,
1200 SENSOR AND DOWNSTREAM PIEZOMETER WITH ISOKINETIC SAMPLING PROBE

3.0 DATA ANALYSIS AND FRACTIONAL EFFICIENCY CALCULATION

During all tests requiring dust feeding, upstream dust concentration levels were controlled to preset values. Particle sizing of the effluent dust was accomplished using the HIAC/ROYCO 4102 light scattering particle size analyzer described above. Samples for the HIAC were withdrawn isokinetically from the centerline of the piezometer tube downstream of the test unit. The HIAC sizing data were used first to calculate numerical and mass concentration levels as a function of geometric particle size (assuming spherical particles), and then to calculate fractional efficiencies with respect to upstream dust levels, and to show the distribution of particles exiting the test unit.

Several downstream particle size measurements were taken during each test run. Raw data for each counting interval (counts per channel per time) and test run were analyzed for goodness of fit to provide a representative average per test. During each particle size measurement, the total concentration of particles present was allocated to six particle size intervals, with the maximum combined range covering threshold sizes from 0.5 to 15 μm , as shown in Table 2. Multiple sets of ranges were chosen during testing to better define the particle size distribution over the entire 0.5 to 20 μm range.

For computing purposes, the geometric midpoint was calculated as:

$$d = 10^{(\log d_2 - \log d_1)} = \sqrt{d_1 \times d_2}$$

to four decimal places. Resulting downstream mass concentrations were then used to compute fractional removal efficiencies with respect to upstream (mass) particle size distributions and concentration values within corresponding size intervals. Test results should be looked at within this framework. As shown in Table 2, three sets of particle size ranges were used, depending on the nature of the downstream particle size distribution (primarily concentration per range) at that particular point of testing.

**TABLE 2. PARTICLE SIZE PARAMETERS FOR
CALCULATING FRACTIONAL EFFICIENCY**

Particle Size Range, μm	Geometric* Midpoint, μm	Upstream** Mass Fraction	Cumulative Fraction
Test 1-3			
1.5-3	2.1213	0.0283	
3-5	3.8730	0.0362	
5-7	5.9161	0.0370	
7-10	8.3666	0.0575	
10-15	12.2474	0.0915	
15-20	17.3205	0.0770	0.3275
Test 4-15			
0.5-1.5	0.8660	0.0175	
1.5-3	2.1213	0.0283	
3-5	3.8730	0.0362	
5-10	7.0711	0.0945	
10-15	12.2474	0.0915	
15-20	17.3205	0.0770	0.3450
Test 16-21			
0.5-2	1.0000	0.0260	
2-5	3.1623	0.0560	
5-8	6.3246	0.0580	
8-11	9.3808	0.0550	
11-15	12.8452	0.0730	
15-20	17.3205	0.0770	0.3450

* Midpoint Diameter = $10^{(\log d_2 - \log d_1)} = \sqrt{d_1 \times d_2}$

** Based on measured particle size distribution supplied with test dust.

4.0 TEST RESULTS

The general test sequence was as follows: measure pressure drop as a function of airflow rate, then conduct efficiency testing at various upstream concentrations, while measuring downstream particle size as required. Test results are presented in Table 1 and Figures 4 through 11. Table 1 gives primary and secondary airflows per test, precleaner pressure drop, upstream dust concentration, gravimetric efficiencies and efficiencies as calculated from the particle size data. In all but one case, geometric efficiency exceeded efficiency predicted by the particle size data, with an average difference of 2.07 percent. The slight discrepancy between these efficiency values is expected and is likely due to a combination of factors associated with the physics of measurement and the dynamics of particle separation and transport. With respect to particle measurement, only six data channels were available for covering a forty to one size range. In addition, particle mass within each interval was calculated from the geometric midpoint, assuming spherical particles. This can misstate the total mass assigned to the interval, especially for ranges near the cut size of the precleaner and for ranges with larger intervals, especially near the upper end of the distribution. Finally, calibration of particle counters is typically accomplished using polystyrene latex spheres (PLS) of known size, as was done in this case. This provides an optical correlation of size to a specific particle, whose characteristics can differ significantly from that of the actual particles being measured. Previous work with similar dust found the white light HIACs to provide results that were in reasonably good agreement with actual particles sizes. Nevertheless, some differences between gravimetric and optically generated efficiencies are to be expected. Because the actual test dust is not spherical, it will affect actual separation performance as well as optical measurement. This is because actual separation performance depends on aerodynamic diameter and particle density rather than physical diameter. Overall, the measurements taken in this project are considered to provide a good representation of downstream particle sizes.

Figure 4 shows pressure drop across the unit as a function of airflow rate for a constant scavenge of 520 scfm. Figure 5 gives gravimetric efficiency as a function of airflow rate for three specific upstream dust concentrations and independent of concentration over the range of 0.00625 to 0.025 g/ft³ air. These values represent averages of all tests in each range and, in the later case, of all tests conducted. The results show a significant inverse dependency on concentration. At lower concentration levels, separation efficiency becomes more sensitive to airflow. With zero visibility dust (0.025 g/ft³ air), gravimetric efficiency is relatively insensitive to airflow rate and only starts to decrease near the higher end of the airflow range. At half zero visibility, sensitivity is still only evident at the higher end of the range, but to a greater extent. Finally, at quarter zero visibility, gravimetric efficiency decreases with flow over the entire airflow range.

Average cumulative downstream mass distributions as a function of particle size are given in Figures 6 through 8. The distribution in Figure 6 is independent of upstream dust concentration and airflow rate. The distribution in Figure 7 is dependent on airflow rate, but independent of concentration, while the distribution in Figure 8 is dependent on concentration and independent of airflow rate. The curves in these figures show that the downstream distributions are nearly log-normal since the particle size data nearly plot out as straight lines in these log-probability graphs. Each figure shows that the mass median diameter is between 5 and 6 μm . For data which are truly log-normally distributed, the geometric mean coincides with the median and the standard deviation is also log-normally distributed, corresponding to the ratio of the 84.1 percent size to the 50 percent size or the 50 percent size to the 15.9 percent size. For these data, the geometric standard deviation is on the order of 1.2 to 1.4.

Fractional efficiency was calculated from the upstream and downstream particle size distributions for given particle size ranges as a function of airflow and inlet dust concentration, as

described in Section 3. Results are given in Figures 9, 10 and 11 for inlet dust concentrations of 0.025, 0.0125 and 0.00625 g/ft³ air, respectively, independent of airflow over the range of 600 to 2,600 scfm primary flow. These results show that the precleaner has an effective cut size ranging from about 3 to 6.5 μm, depending on concentration and airflow rate. This is the particle size where the probability of particle collection is 50 percent. In all cases, collection efficiency was 90 percent or better at 10 μm and 99 percent or better at 15 μm.

The calculated fractional efficiency values tended to level below 5 μm and rose in the range between 4 and 0.5 μm. This is considered an aberration caused most likely by over estimating the upstream concentration in the small size ranges because of upstream agglomeration or incomplete particle dispersion, both of which will actually increase physical separation efficiency as well as skew the results by presenting significantly less downstream particles to the analyzer in these ranges. Because mass is proportional to the diameter cubed, these two events, by removing and altering particles in the lower size ranges, will significantly overstate the actual upstream mass in these channels compared to that assumed from the dust calibration data, if fully dispersed and remaining unagglomerated. Overstating the upstream mass in these lower ranges while understating the downstream mass that would have been present in the absence of agglomeration or incomplete dispersion, would significantly overstate fractional efficiency in these ranges. This would also have some impact on immediate neighboring channels, but to a much lesser extent as the agglomeration or dispersion affects, if present, rapidly diminish with increasing particle size. This was apparent from the overlapping ranges and was one of the reasons for their selection during testing. Considering the shape of typical efficiency versus particle size curves for high efficiency inertial separators, the data given in Figures 9, 10 and 11 seem representative and reasonable, especially when plotted on standard graph paper rather than on log probability paper, which was chosen here to allow clear inspection of the data at the higher end of the curve.

The assumptions of sphericity and geometric midpoint for the calculation of downstream mass also affect the fractional efficiency determinations. Collection efficiency curves for inertial separators are often plotted in terms of efficiency versus the square root of Stokes number, which is directly proportional to particle size, or with respect to aerodynamic diameter, which is the diameter of a unit density sphere (for instance, a small water droplet) that has the same settling velocity as the particle in question. Stokes diameter, is the diameter of a sphere that has the same density and settling velocity as the particle. Stokes diameter standardizes particles of various shapes to the same aerodynamic property, settling velocity, while aerodynamic diameter standardizes for both shape and density. The two are related mathematically as:

$$d_a = d_s(\rho_p/\rho_0)^{1/2}$$

where ρ_0 is unit density. Although both are defined in terms of their aerodynamic behavior in the separator, aerodynamic diameter is more commonly used. The important point here is that for the usual case of a sphere with density greater than 1 g/cm³, the aerodynamic diameter is always greater than the physical diameter. For the dust in question, the density is 2.65 g/cm³, which gives, for comparison, an aerodynamic cut size on the order of 5 to 10 μm for the Turbodyne II unit, depending on upstream concentration and airflow rate. Measuring the downstream distributions using a set of cascade impactors would yield this result directly, however using these devices is much more cumbersome and time consuming than using an optical particle counter

In summary, it is expected that calculated results based on particle sizing will likely differ slightly from results obtained by gravimetric (absolute filter) analysis, for a number of reasons. First, in this case, the optical particle size measurement was extractive, whereby a continuous sample of air was drawn from the effluent air stream and transported to the optical sensing zone of the

instrument. With this arrangement, particle sampling errors and particle transport losses in the tubing are possible even when great care is taken. Second, sensed particles can be incorrectly sized because instrument calibration and the assigned "particle sizes" are typically based on light scattered by non-absorbing, spherical particles, during calibration runs using monodispersed particles. Irregular, absorbing particles, such as those comprising the SAE Coarse test dust used here will scatter light differently, which could lead to a slight sizing error. As a matter of note, this type of error is generally small for this particular instrument. Finally, the optical particle counter senses number concentration, hence mass concentration must be inferred by mathematical calculation, which in this case assumed spherical particles. Fractional mass efficiency calculations also assume complete dispersion of the upstream dust so that the entire upstream particle size distribution is presented to the precleaner.

Nevertheless, results based on particle sizing are significant because the trends obtained are reasonably accurate, and because the dependency of performance on particle size is readily apparent. The trends observed during these tests are consistent with the fact that most air precleaners are sensitive to operating and scavenge airflow, and upstream concentration levels and particle sizes.

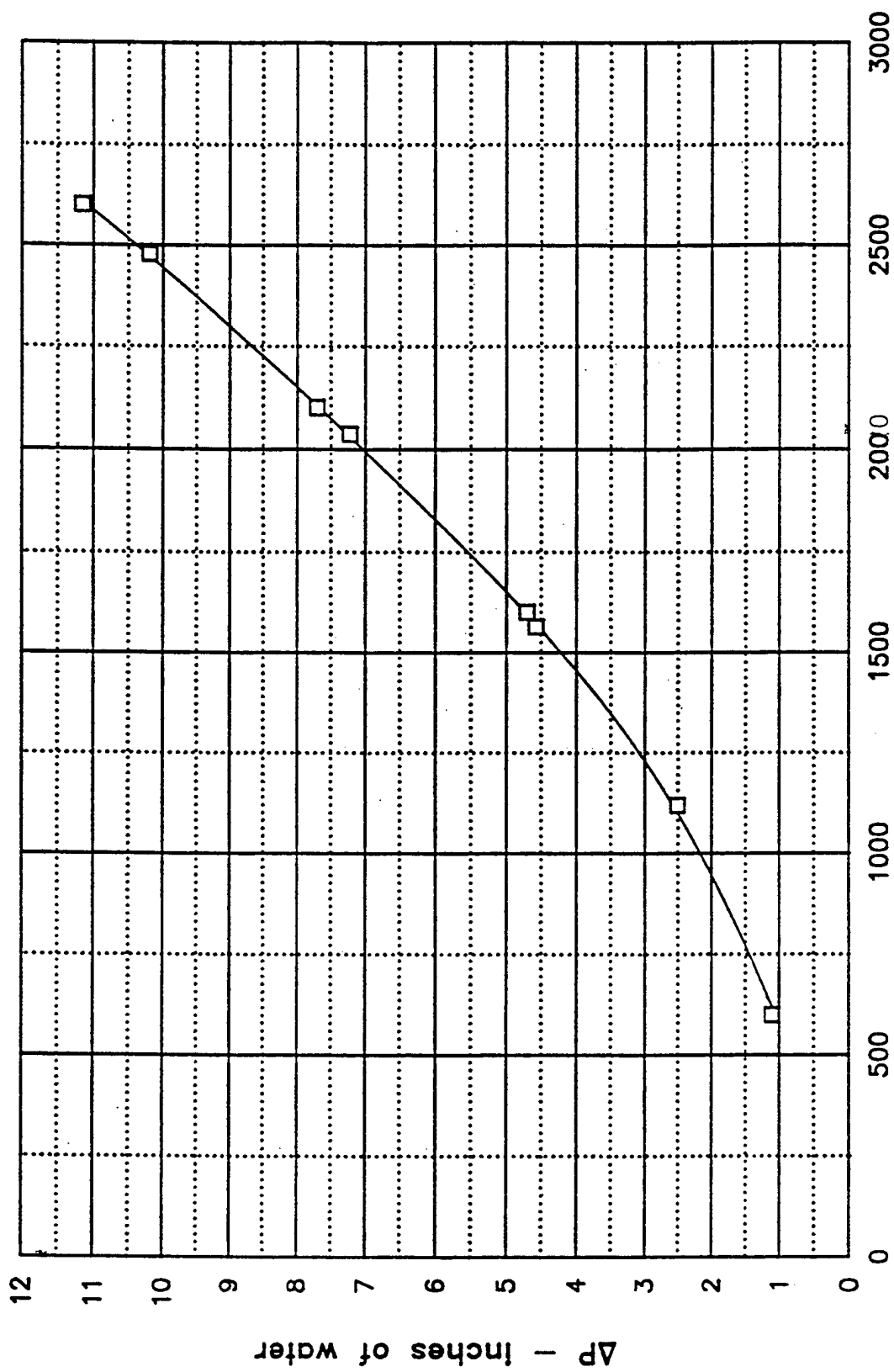


FIGURE 4. PRESSURE DROP AS A FUNCTION OF AIRFLOW RATE; TURBODYNE II
PRECLEANER (CENTRISEP CE 00852-1D9, S/N A001)

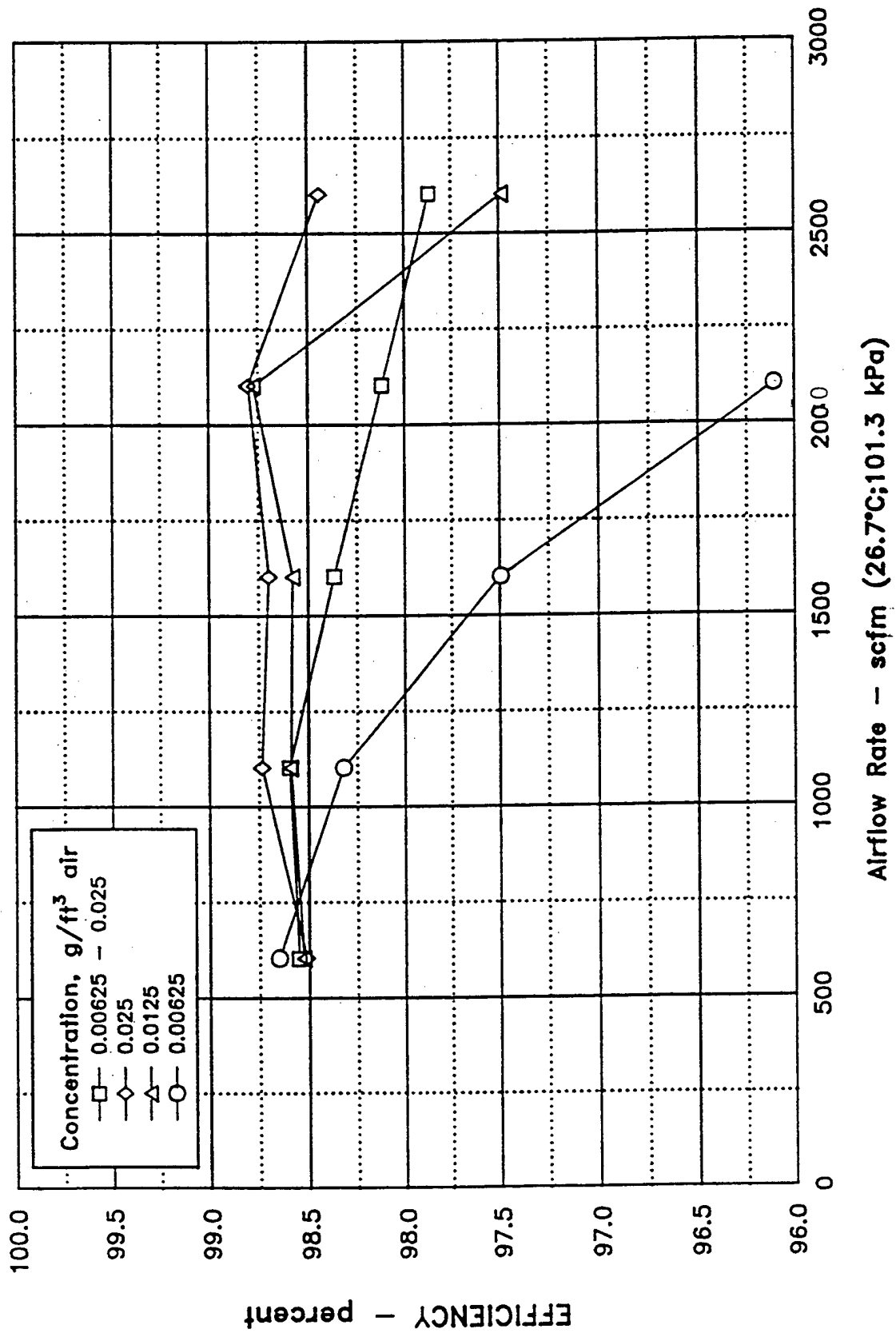


FIGURE 5. GRAVIMETRIC EFFICIENCY AS A FUNCTION OF AIRFLOW RATE; TURBODYNE II
PRECLEANER (CENTRISEP CE 00852-1D9, S/N A001)

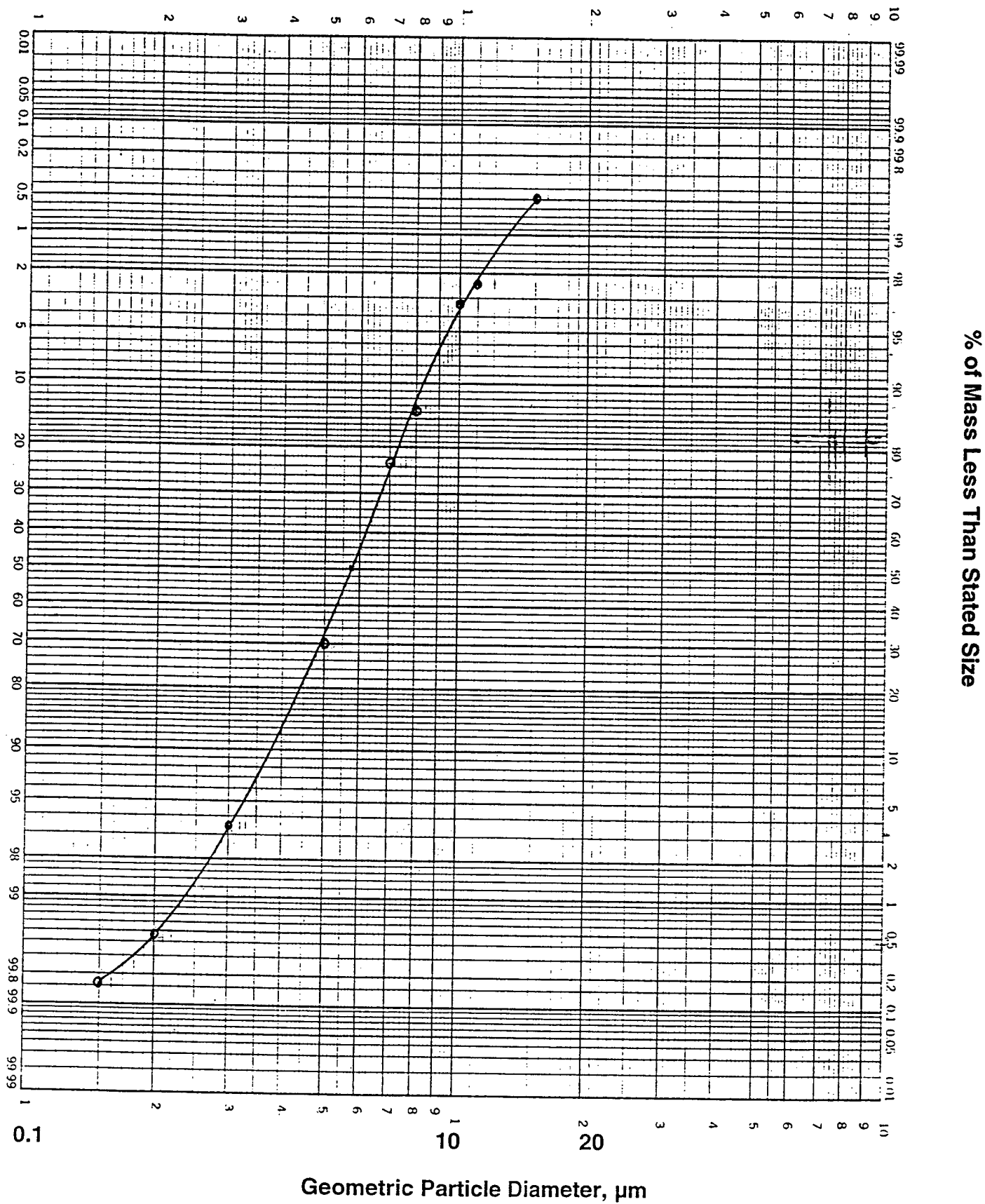


FIGURE 6. AVERAGE CUMULATIVE DOWNSTREAM MASS DISTRIBUTION AS A FUNCTION OF PARTICLE SIZE; INDEPENDENT OF CONCENTRATION AND AIRFLOW RATE

% of Mass Less Than Stated Size

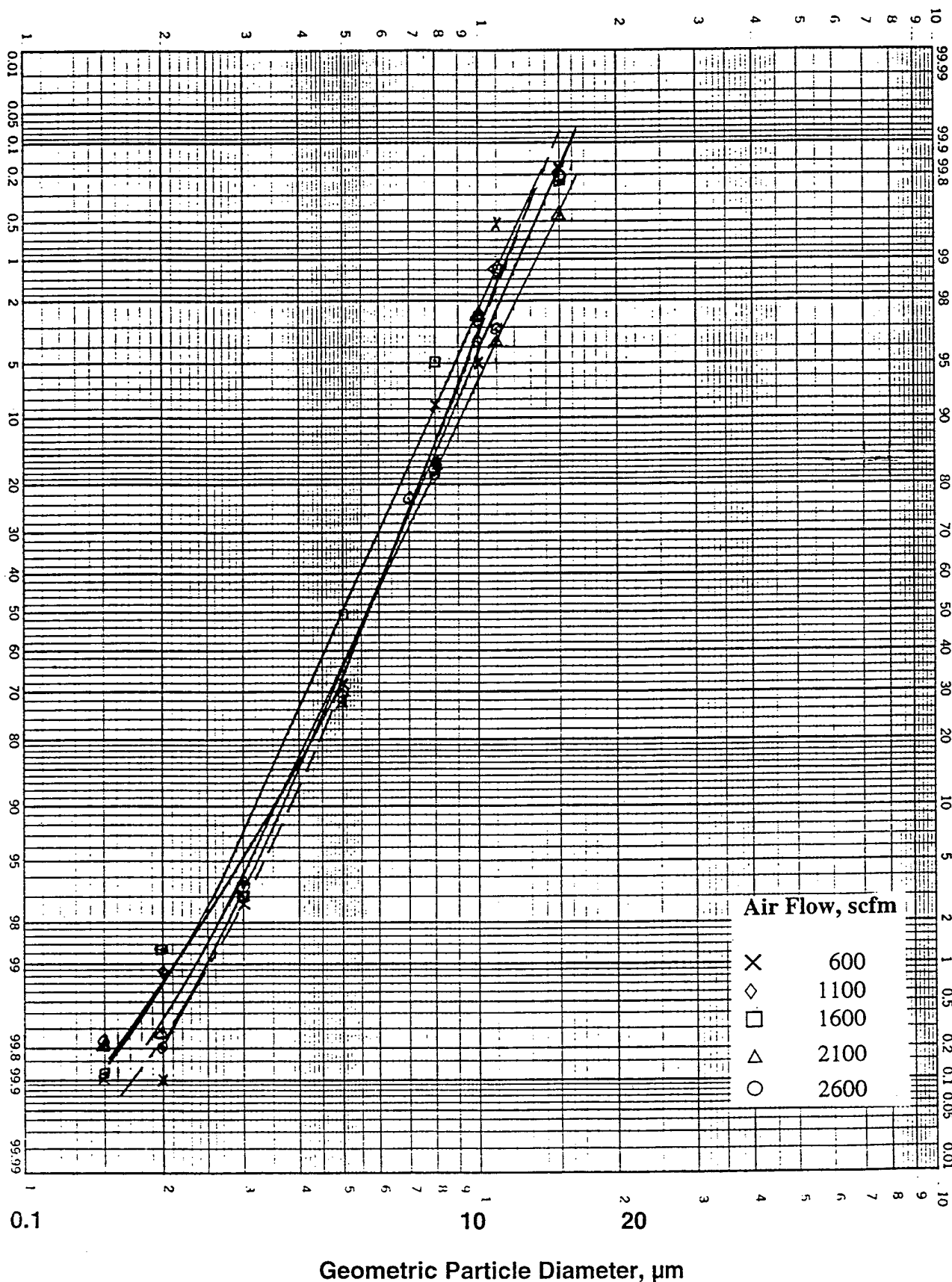


FIGURE 7. AVERAGE CUMULATIVE DOWNSTREAM MASS DISTRIBUTION AS A FUNCTION OF PARTICLE SIZE AND AIRFLOW RATE; INDEPENDENT OF CONCENTRATION

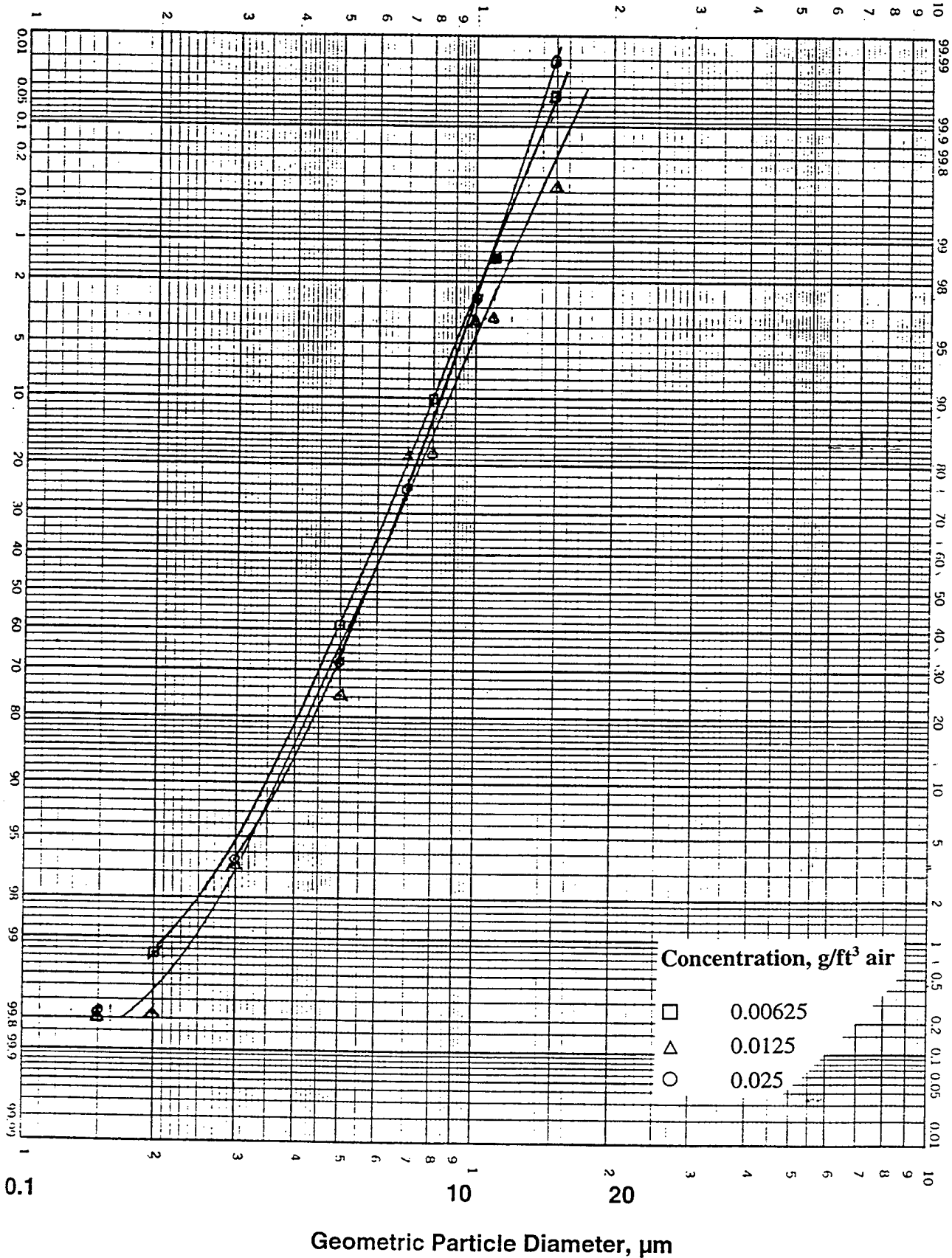


FIGURE 8. AVERAGE CUMULATIVE DOWNSTREAM MASS DISTRIBUTION AS A FUNCTION OF PARTICLE SIZE AND CONCENTRATION; INDEPENDENT OF AIRFLOW RATE

Fractional Efficiency, %

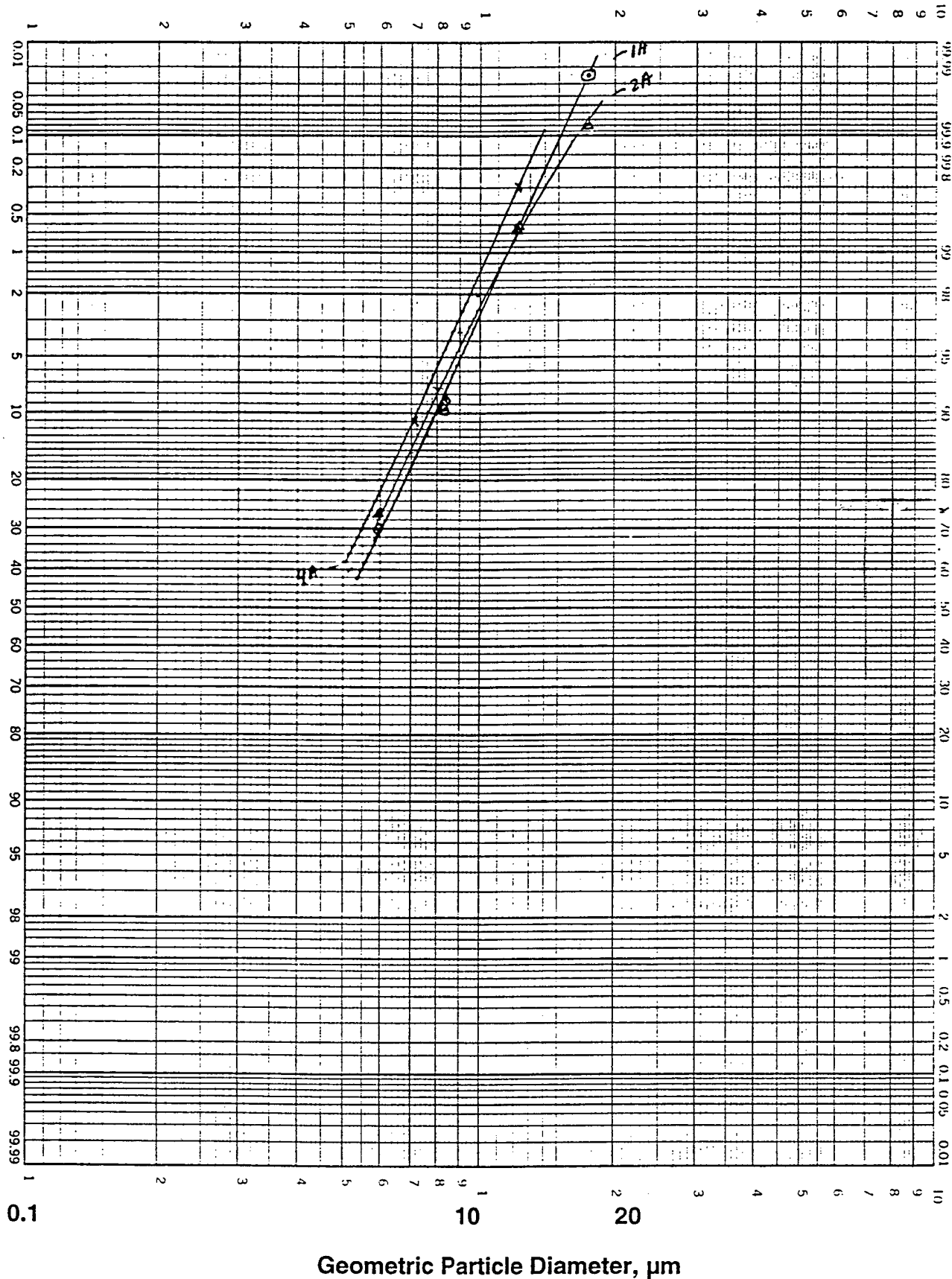


FIGURE 9. FRACTIONAL EFFICIENCY AS A FUNCTION OF PARTICLE SIZE FOR UPSTREAM DUST CONCENTRATION OF 0.025 GRAMS PER CUBIC FOOT AIR; INDEPENDENT OF AIRFLOW RATE

Fractional Efficiency, %

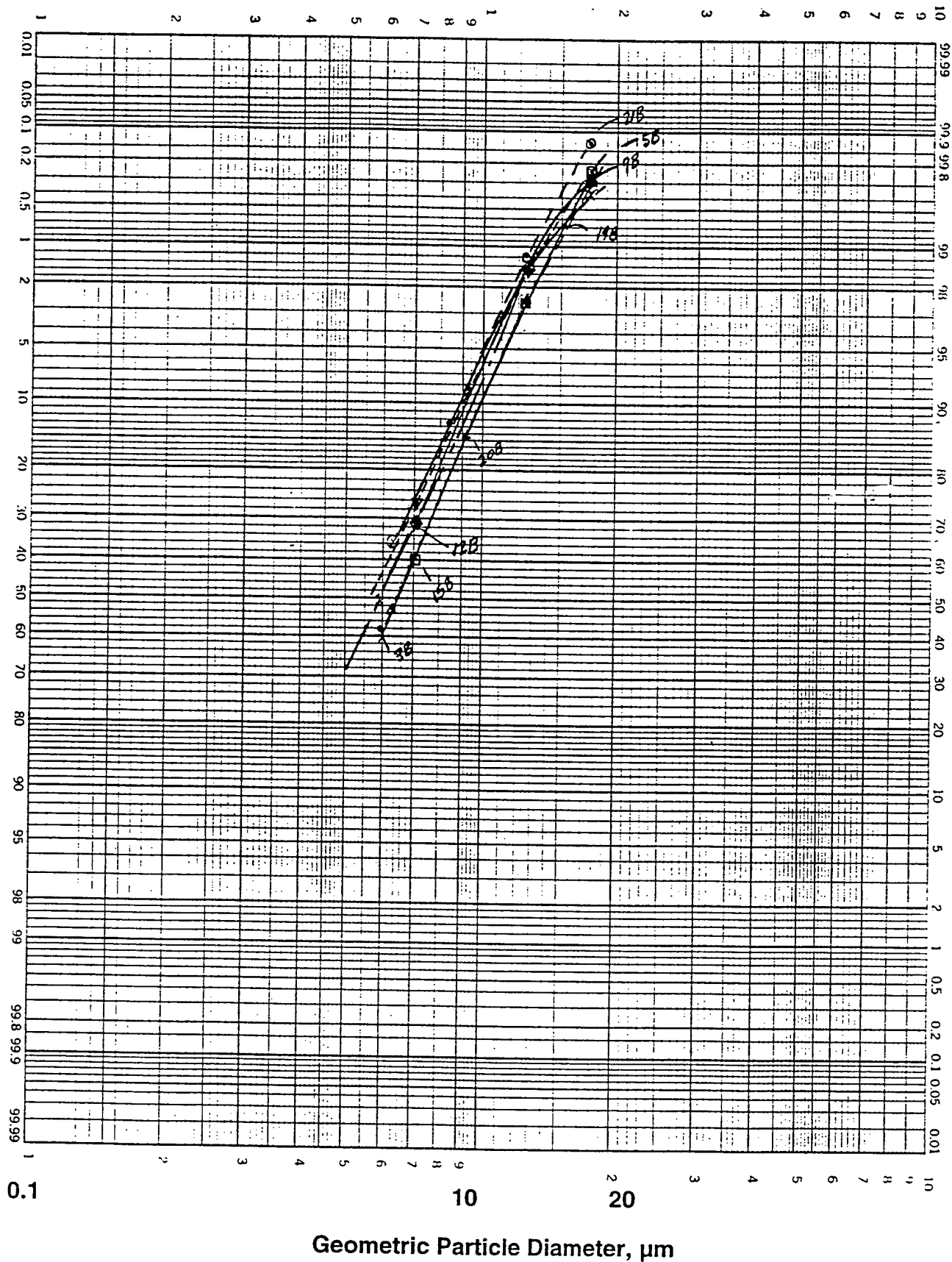


FIGURE 10. FRACTIONAL EFFICIENCY AS A FUNCTION OF PARTICLE SIZE FOR AN UPSTREAM DUST CONCENTRATION OF 0.0125 GRAMS PER CUBIC FOOT AIR; INDEPENDENT OF AIRFLOW RATE

Fractional Efficiency, %

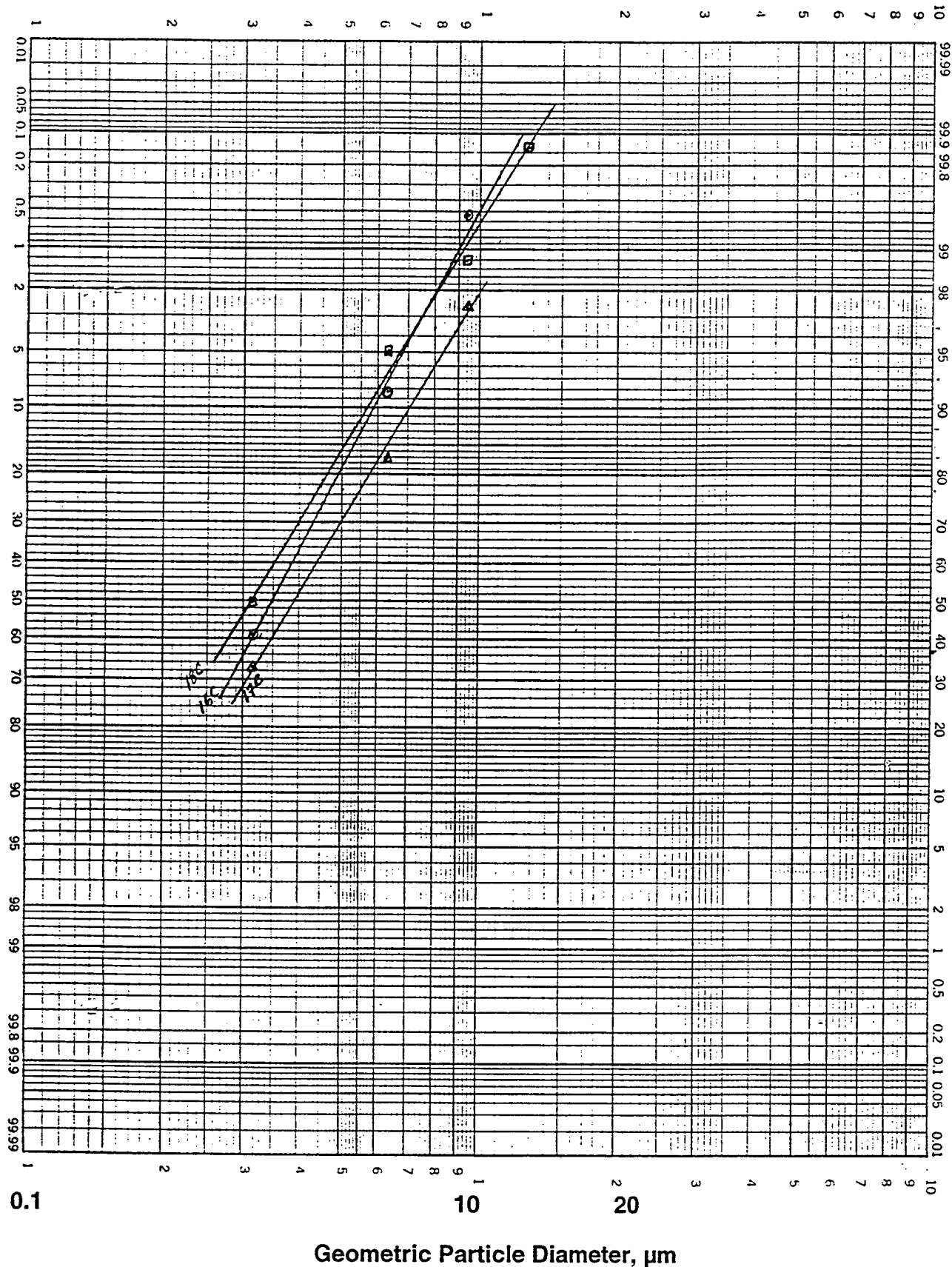


FIGURE 11. FRACTIONAL EFFICIENCY AS A FUNCTION OF PARTICLE SIZE FOR
UPSTREAM DUST CONCENTRATION OF 0.00625 GRAMS PER CUBIC FOOT AIR;
INDEPENDENT OF AIRFLOW RATE

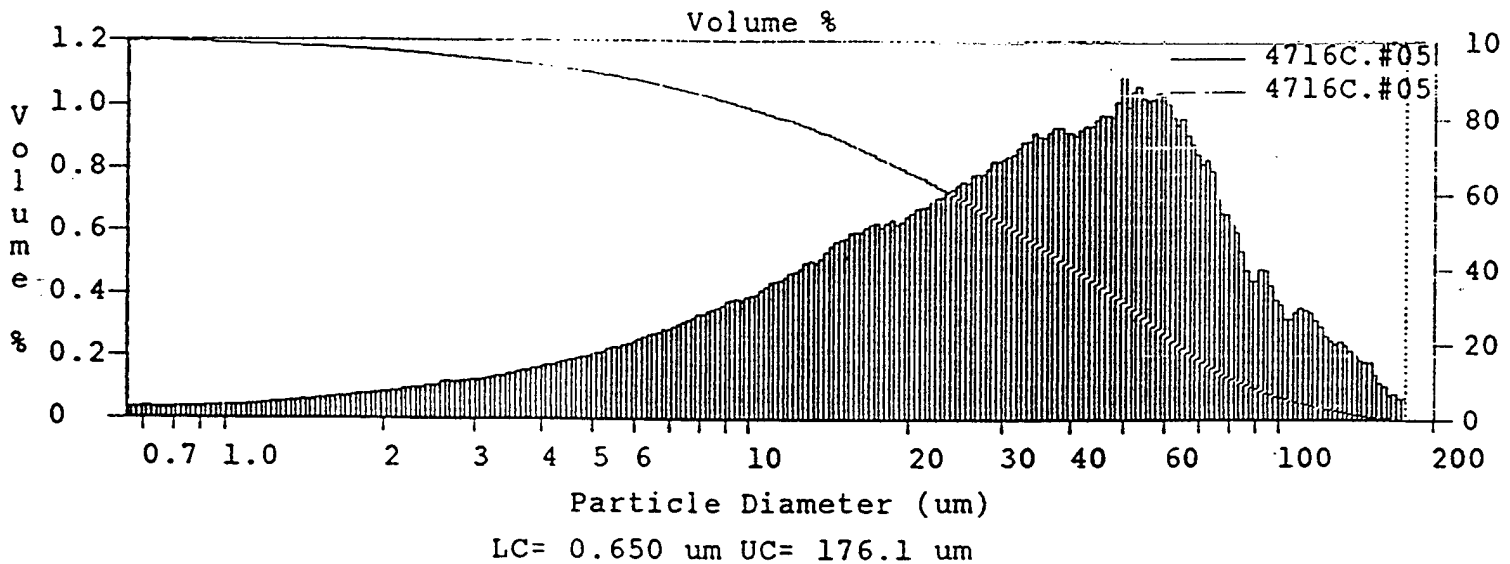
ATTACHMENT

Filename: 4716C.#05
 Group ID: 4716C
 Sample ID: ISO 12103-1, A4 COARSE TEST DUST
 Comments: SAE COARSE TEST DUST
 Operator: TAF
 Electrolyte: ISOTON II
 Dispersant: TYPE IC
 Aperture Size: 400 um 4716C.#01
 200 um 4716C.#02
 100 um 4716C.#03
 30 um 4716C.#04

Sample Number: 111

P.O. Box 1464
 Burnsville, Minnesota 55337
 Phone: (612) 894-8737

Channels 256 Variable 1: 0.000000
 Variable 2: 0.000000
 Acquired at: 16:17 Sun Jun 15 1997



Volume Statistics (Geometric)

4716C.#05

Calculations from 0.65 um to 176.11 um
 Volume 6.412×10^9 um³
 Mean: 25.82 um
 Median: 31.54 um
 Mean/Median Ratio: 0.819
 Mode: 50.04 um

Std. Dev.: 1.055
 Variance: 1.113

Cumulative Volume Numeric Data
 Micron Size % Greater Than

1	99.3
2	97.3
3	95.4
4	93.6
5	91.7
7	87.9
10	82.4
20	65.7
40	40.2
80	10.8
120	3.0
180	0.0

4716C.#05

Channels	Particle Diameter um	Diff Number %	Cum > Number %	Diff Volume %	Cum > Volume %	
1	0.65	22.43	100.00	0.17	100.00	0
6	0.73	15.89	77.57	0.17	99.83	0.17
11	0.81	12.23	61.68	0.18	99.66	0.3
16	0.90	9.65	49.45	0.20	99.48	0.52
21	1.01	7.79	39.80	0.22	99.28	0.72
26	1.12	6.29	32.00	0.25	99.06	0.9
31	1.25	5.09	25.71	0.28	98.81	1.19
36	1.40	4.07	20.62	0.31	98.53	1.47
41	1.56	3.28	16.55	0.35	98.22	1.7
46	1.74	2.62	13.27	0.39	97.87	2.1
51	1.94	2.11	10.64	0.43	97.49	2.51
56	2.17	1.72	8.53	0.49	97.06	2.94
61	2.42	1.41	6.81	0.55	96.57	3.43
66	2.70	1.09	5.40	0.59	96.02	3.98
71	3.01	0.86	4.31	0.65	95.42	4.58
76	3.35	0.69	3.45	0.73	94.77	5.23
81	3.74	0.56	2.76	0.81	94.04	5.96
86	4.18	0.45	2.20	0.91	93.23	6.77
91	4.66	0.36	1.75	1.00	92.32	7.68
96	5.20	0.29	1.40	1.12	91.32	8.68
101	5.80	0.23	1.11	1.25	90.19	9.81
106	6.47	0.18	0.88	1.39	88.94	11.06
111	7.22	0.15	0.70	1.57	87.55	12.45
116	8.05	0.12	0.55	1.72	85.98	14.02
121	8.98	0.09	0.43	1.90	84.26	15.74
126	10.02	0.07	0.33	2.05	82.35	17.65
131	11.18	0.06	0.26	2.26	80.30	19.70
136	12.47	0.05	0.20	2.48	78.04	21.96
141	13.91	0.04	0.16	2.80	75.55	24.45
146	15.52	0.03	0.12	3.02	72.75	27.25
151	17.32	0.02	0.09	3.12	69.73	30.27
156	19.32	0.02	0.07	3.28	66.61	33.39
161	21.55	0.01	0.05	3.52	63.32	36.68
166	24.04	0.01	0.04	3.78	59.80	40.20
171	26.82	0.01	0.03	4.02	56.03	43.97
176	29.92	0.01	0.02	4.27	52.01	47.99
181	33.38	0.00	0.02	4.51	47.74	52.26
186	37.24	0.00	0.01	4.59	43.23	56.77
191	41.55	0.00	0.01	4.71	38.64	61.36
196	46.35	0.00	0.01	5.03	33.93	66.07
201	51.71	0.00	0.00	5.16	28.91	71.09
206	57.69	0.00	0.00	4.97	23.75	76.25
211	64.36	0.00	0.00	4.40	18.78	81.22
216	71.80	0.00	0.00	3.64	14.38	85.62
221	80.11	0.00	0.00	2.66	10.73	89.27
226	89.37	0.00	0.00	2.20	8.07	91.93
231	99.70	0.00	0.00	1.70	5.87	94.13
236	111.23	0.00	0.00	1.56	4.17	95.83
241	124.09	0.00	0.00	1.19	2.61	97.39
246	138.44	0.00	0.00	0.90	1.41	98.59
251	154.44	0.00	0.00	0.45	0.52	99.48

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