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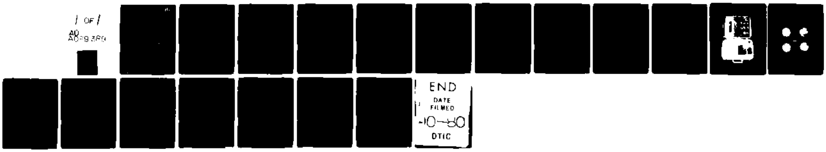

PARTICULATE DISTRIBUTIONS IN THE GARFIELD THOMAS 48-INCH DIAMETER WATER TUNNEL

G. C. Lauchle and J. B. Crust

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A series of water samples were collected from the test section of the Garfield Thomas 48-inch diameter water tunnel and analyzed for particulate shape, size, and elemental composition. These collections took place over a two week period of time and over a range of test section flow conditions. The analyses have shown that the standard deviation of the particulate average diameter is 2.1 microns, that they are typically non-spherical in shape with an average fineness ratio of 0.65, and that the major elements are aluminum

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20. and silicon with minor and trace elements consisting of chlorine, calcium, iron, nickel and zinc.

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Abstract: A series of water samples were collected from the test section of the Garfield Thomas 48-inch diameter water tunnel and analyzed for particulate shape, size, and elemental composition. These collections took place over a two week period of time and over a range of test section flow conditions. The analyses have shown that the standard deviation of the particulate average diameter is 2.1 microns, that they are typically non-spherical in shape with an average fineness ratio of 0.65, and that the major elements are aluminum and silicon with minor and trace elements consisting of chlorine, calcium, iron, nickel, and zinc.

Acknowledgements: This work represents a ~~final~~ report for Task 3 of ARL/PSU proposal 1074 which is being supported by the Improved Performance Undersea Vehicle (IPUV) Block Program, Naval Underwater Systems Center, Newport, RI. The continued support by the Naval Sea Systems Command, Code NSEA 63R31 for tasks related to laminar flow technology is also gratefully acknowledged.

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INTRODUCTION

The Garfield Thomas 48-inch diameter high-speed water tunnel [1]* has and continues to be used in fundamental experimental research on laminar flow technology. Current research deals with the stabilization of the laminar boundary layer by wall heating, while the course of events suggests that surface suction may be investigated in future programs. With either type of boundary layer control, it is well recognized that several types of free-stream disturbances can be detrimental to its effectiveness. Those disturbances considered most important are free-stream turbulence and particulates. The free-stream turbulence characteristics were recently measured and reported by Robbins [2], while in this report, measurements of particulate distribution are described. These particulate data represent baseline data and may have immediate application in the design of surface suction test vehicles for which testing in the Garfield Thomas Water Tunnel is anticipated.

PROCEDURE

A standard procedure for measuring particulate distribution is to pass randomly selected volumes of the subject water through a filtering apparatus and to then analyze, statistically, the particles that have remained on the filter. The filtering apparatus which we have used in this program is known by the trade name: *Bomb Sampling Kit* (Figure 1) manufactured by Millipore Filter Corp., Bedford, Massachusetts. Because the filters supplied with this kit were too coarse for the sizes of particulates anticipated in the water tunnel water, Nuclepore® filters of 1 micron pore size were acquired. The effective filter area was 4300 mm^2.

Several water outlet valves are available on the 48-inch water tunnel. One located adjacent to the upstream end of the test section was selected for 90% of the samples. The remaining samples were taken from the lower leg of the tunnel. Only those data for the test section will be presented because the valve used in the lower leg was believed to be corroded which, of course, would contribute to biased data.

The Bomb Sampler was used as follows for each of the water samples collected over a two week period in July 1980.

1. The Bomb Sampler was unscrewed. After the red and blue plugs from the plastic monitor were removed, the monitor was inserted "spoke-side" down into the Bomb Sampler.

2. The Bomb Sampler was then tightly screwed together, and the bypass hose from the three-way valve was connected to either hole in the side of the Bomb Sampler.

3. The 850 milliliter polyethylene sampling bottle was attached to the base of the Bomb Sampler.

*Numbers in brackets designate references at end of paper.

4. With the three-way valve in the "off" position, the Bomb Sampler was connected to the Tygon tubing, which was previously attached to the tunnel's outlet valve.

5. The three-way valve was turned to the "flush" position and 200 milliliters of water were bypassed to remove any entrained contaminants from the Bomb Sampler.

6. The three-way valve was turned to the "test" position and 500 milliliters of water were passed through the monitor.

7. The Bomb Sampler was disconnected and the dust plugs were replaced.

8. The monitor was removed from the Bomb Sampler and pumped dry with the syringe. The red and blue protective plugs were then replaced.

The filter was then removed from the monitor with forceps and placed in a petri dish. Subsequent analysis was then performed by the staff at the Pennsylvania State University, Materials Research Laboratory.

A section of the filter was mounted on a carbon disc using a silver colloid solution to secure the filter (Figure 2). The disc was then placed in a vacuum and a thin film of ionized gold particles were placed on the filter. This was required to provide a conducting surface for the electron beam of a scanning electron microscope. Next, the disc was placed in the scanning electron microscope (SEM). A PDP11-20 computer, which was connected interactively with the SEM, monitored and controlled the scanning. A number of 300 x 300 micron frames were scanned at a magnification of 300X. The computer then analyzed and printed out the size and shape distributions of the particles. At the same time, the chemical make-up of the particles was also analyzed. This elemental analysis, however, excluded those elements with atomic numbers below eleven (sodium).

RESULTS

Because of mixing, one would anticipate that the particulate distributions would depend to some extent on the flow rate in the tunnel. Therefore, water samples were collected while the tunnel was operated over a range of test section velocities. Figure 3 shows the average particulate diameter distributions for a range of velocities as noted on the figure. The average diameter of a given particulate was determined from the SEM through multiple scans. The ordinate of this figure is an estimate based on the number of particles counted over the scanned area of the filter and on the volume of water that passed through the filter. Upon examination of the data of Figure 3, no definitive statements regarding the dependence of the distributions on flow velocity can be made. Within the bounds of experimental data scatter (random errors), the distributions are independent of tunnel speed. As shown in the legend, the standard deviation (rms value), σ, falls between 1.9 and 2.4 microns. An average of these rms values is 2.1 microns. The distributions are skewed slightly to the high side because the Nuclepore filter can pass particles less than 1 micron in diameter. Above 25 microns, there were no particles captured because this is the size filter used in the water tunnel for routine filtering during fill, drain, and bypass operations.

The "peak" in Figure 3 occurs at about 2.0 microns, where we note a peak value of 10^6 particles per liter. Assuming a spherical particle of diameter equal to 2 μm, we calculate a total volume displaced by the particles to be 5.236×10^{-13} m^3 for every liter of water. Thus, the 2 μm particles occupy approximately 5.2×10^{-8} percent of the water volume.

Figure 4 shows the particulate shape distributions expressed in terms of the fineness ratio: minimum diameter/maximum diameter. Clearly, all collected particles are non-spherical with an average fineness ratio of 0.65. There are also a measurable number of particles with very low fineness ratios ($D_{min}/D_{max} < 0.3$). The origin of these particles cannot be hypothesized from the current method of analysis.

With regards to chemical makeup, however, the SEM analysis does provide a relative measure of the elemental content of the particles collected on the filter. Figure 5 shows the results of this analysis. Clearly, the major elements are aluminum and silicon while minor elements include chlorine, calcium, iron, nickel, copper, and zinc. The silicon can be identified as tunnel "seeds" (1.5 μm in size) which are routinely injected into the tunnel in order to enhance laser doppler anemometry studies. It is speculated that the aluminum is a result of residues left over from an aluminum honeycomb which deteriorated in the mid-1960's [2]. Obviously, the chlorine and calcium are due to the fact that community water is used in the tunnel while the iron is due to ferrous oxidation. Because the test section is brass, we suspect that the copper and zinc traces may be attributed to this alloy. A single source for the nickel trace is difficult to identify, so it is suggested that its buildup has resulted from the residues of the many different alloys that have been used in the fabrication of test models over the years, e.g. stainless steel.

SUMMARY AND RECOMMENDATIONS

Over a two week period of time in July 1980, samples of water were drawn from the 48-inch diameter water tunnel and filtered with a 1.0 μm filter. The particles collected on the filter were analyzed using a scanning electron microscope. It was found that the standard deviation of the particles' average diameter is 2.1 microns, that the particles are non-spherical in shape with a typical fineness ratio of 0.65, and that the major constituency of these particles is aluminum and silicon.

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In noting that no particles greater than 25 microns in size were collected suggests that the filter system currently used for the water of the 48-inch diameter water tunnel is operating satisfactorily. Since 1977, 25 micron filters have been used for this routine filtering. Because they are due to be changed soon, it has been recommended that a 10 micron size filter be used. After another 6 to 8 months, the tests reported here are to be repeated and the data compared to assess whether improvements can or have been made. It is emphasized that the water in its current state is quite clean, but if additional improvement can be made, at little additional expense, then that improvement can only provide a more reliable test environment in which laminar flow research can be carried out.

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[2] Robbins, B. E., "Water Tunnel Turbulence Measurements Behind a Honeycomb," J. Hydronuatics, 12, pp. 122-128, July 1978.

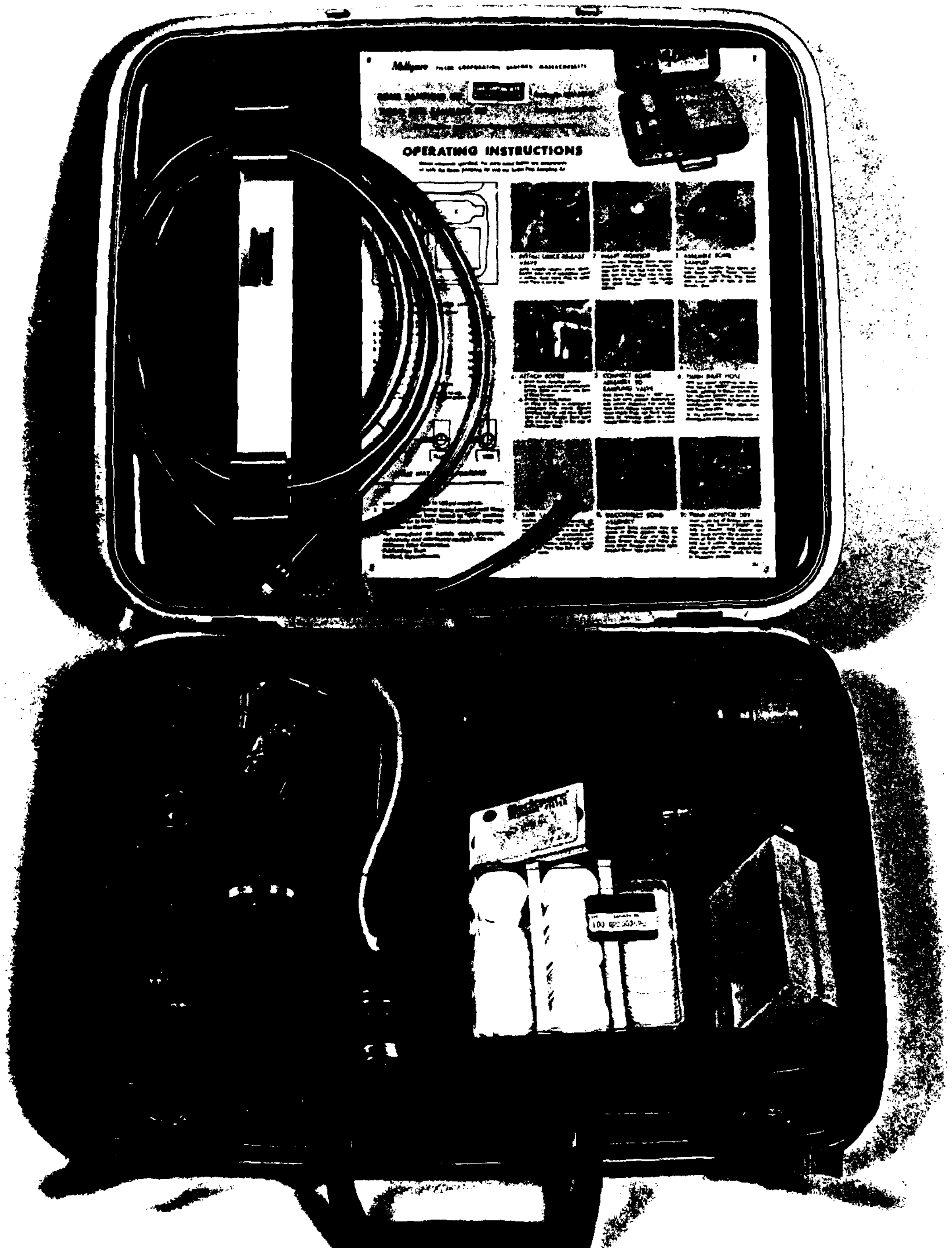
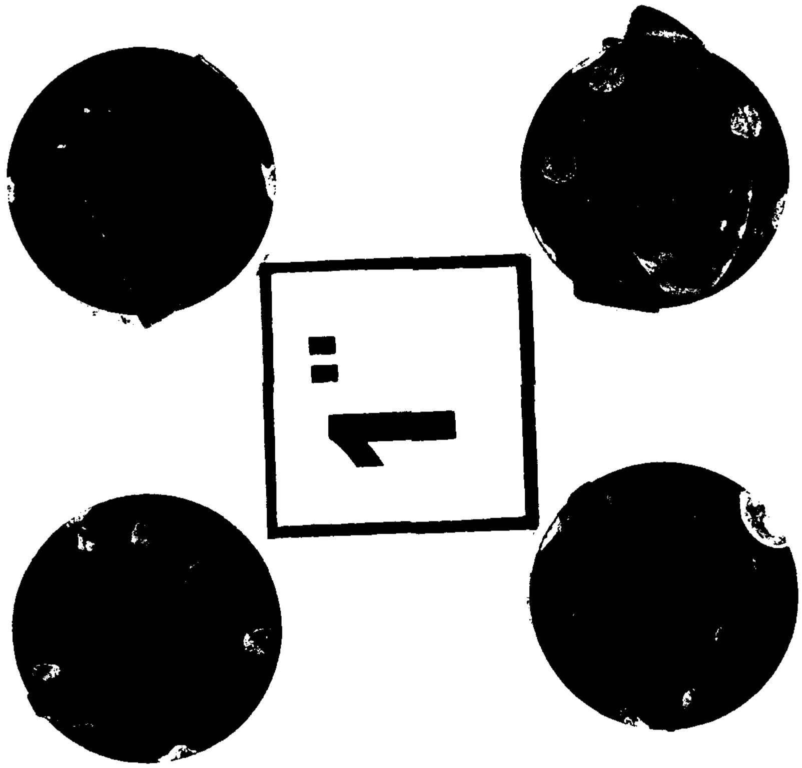


Figure 1 - Photograph of the Millipore [illegible] Sampling Kit



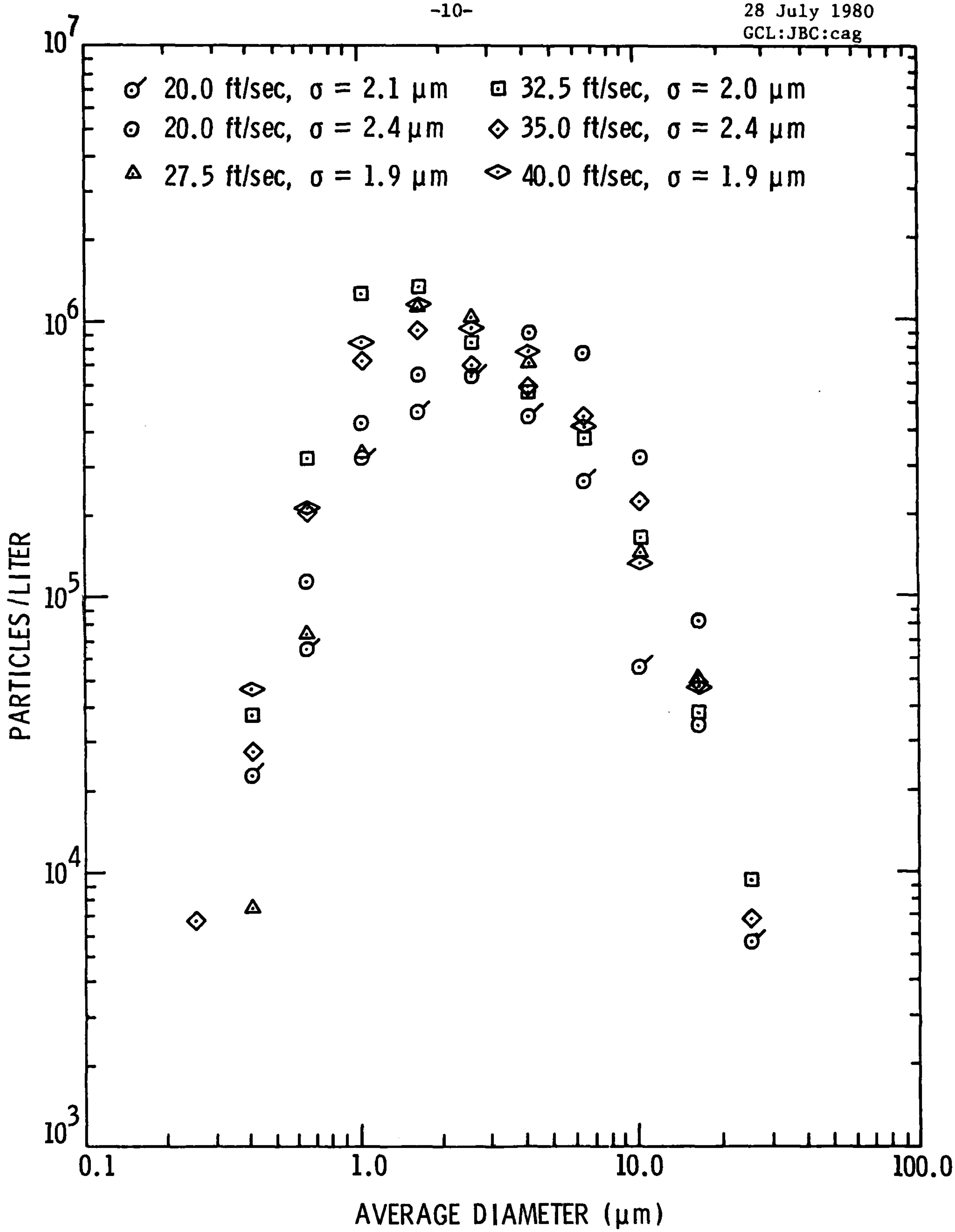


Figure 3 - Particulate Size Distributions for Various Flow Conditions

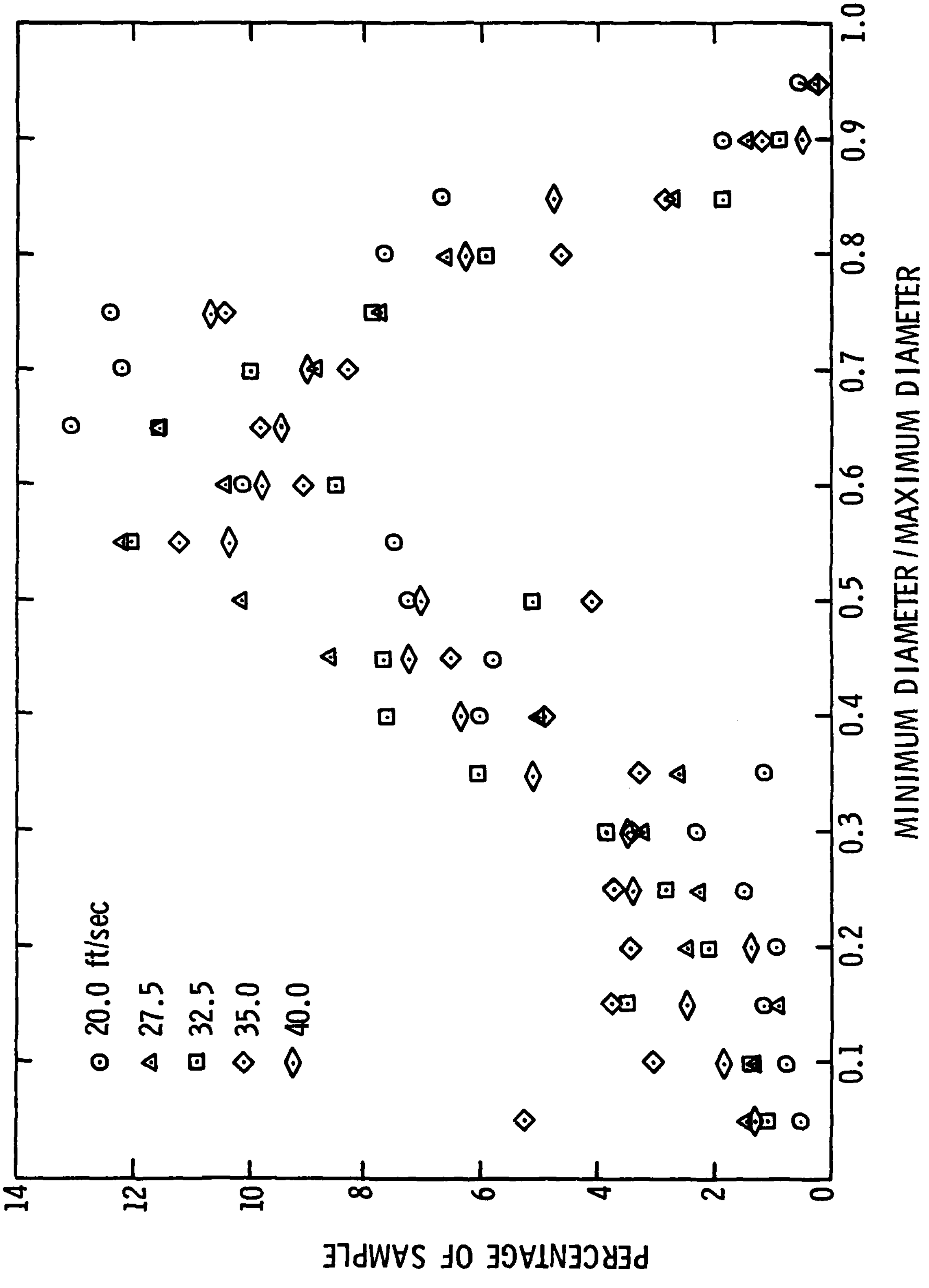


Figure 4 - Particulate Shape (Fineness Ratio) Distributions for Various Flow Conditions

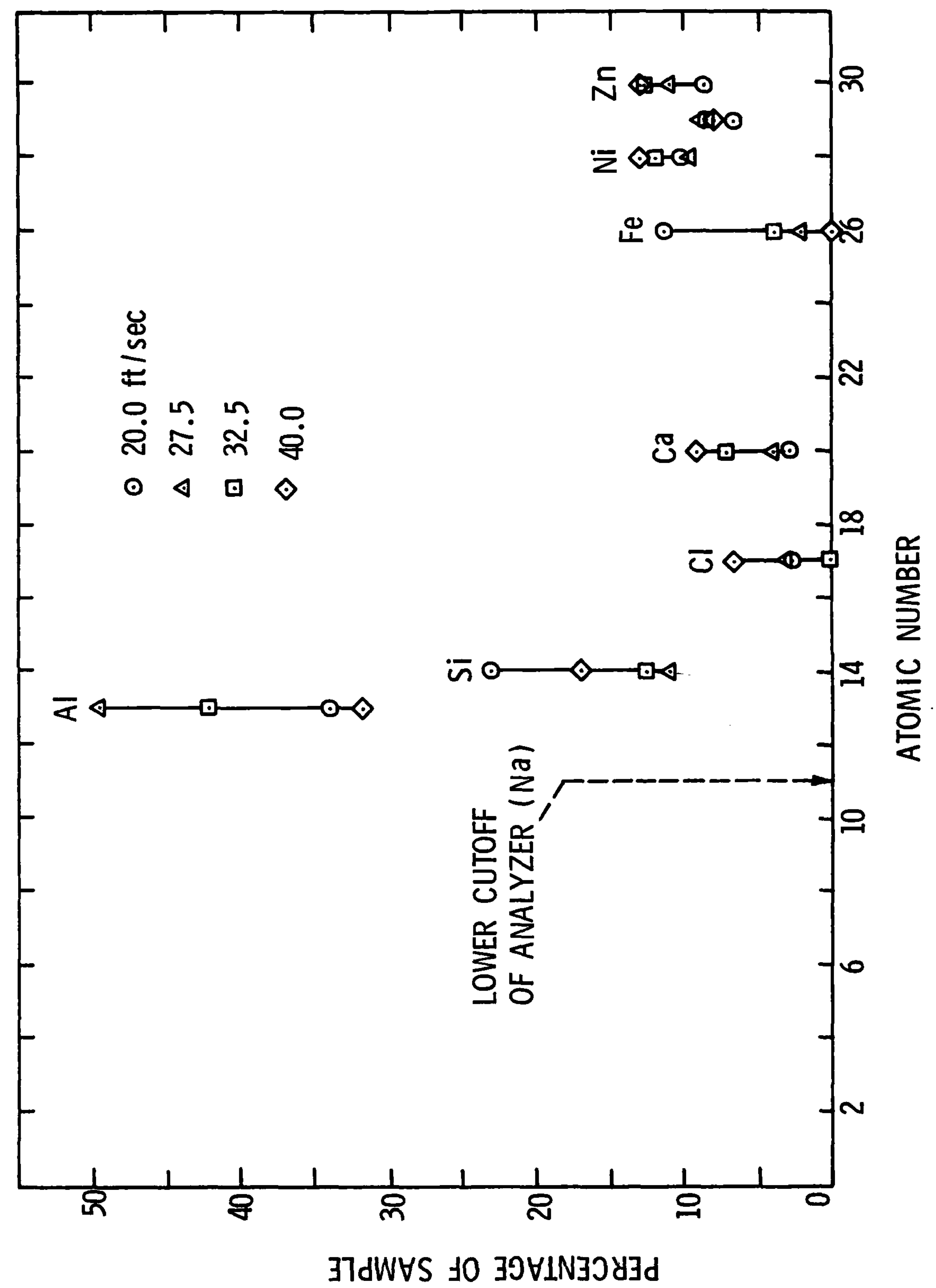


Figure 5 - Elemental Distributions for Particulates Collected Under Various Flow Conditions

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