Title

Reduced Worker Exposure and Improved Energy Efficiency in Industrial Fume-Hoods Using an Airvest

Authors

Gadgil, A J

Faulkner, D

Fisk, W J

Publication Date

1992-05-01

LBL-32244
UC-406

Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

ENERGY & ENVIRONMENT DIVISION

To be presented at the 1992 Indoor Air Quality Conference,
San Francsico, CA, October 18-21, 1992,
and to be published in the Proceedings

Reduced Worker Exposure and Improved Energy Efficiency in Industrial Fume-Hoods Using an Airvest

A.J. Gadgil, D. Faulkner, and W. J. Fisk

May 1992

ENERGY & ENVIRONMENT DIVISION

Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098

DISCLAIMER

LBL-32244

To be presented at and published in the Proceedings
of ASHRAE, AIHA and ACGIH conference,
IAQ'92, October 18-21, 1992, San Francisco, CA

REDUCED WORKER EXPOSURE AND IMPROVED ENERGY EFFICIENCY IN INDUSTRIAL FUME-HOODS USING AN AIRVEST

Ashok J. Gadgil, David Faulkner, and William J. Fisk

Indoor Environment Program,
Energy and Environment Division
Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

May, 1992

This work was supported by Director's Discretionary Funds Grant by the California Institute for Energy Efficiency through grant number BG 90-225, and partially by the Assistant Secretary for Conservation and Renewable Energy, Office of Building Technologies, U.S. Department of Energy under contract DE-AC03-76SF00098, and a U.C. Berkeley Faculty Research Funds Award to Professor A. H. Rosenfeld.

To be presented at
ASHRAE conference IAQ'92,
October 18-21, 1992, San Francisco, CA

Reduced Worker Exposure and Improved Energy-efficiency in Industrial Fume-hoods using an Airvest

Ashok J. Gadgil, Ph.D., David Faulkner, and William J. Fisk (member ASHRAE)

ABSTRACT

Reduction in the breathing zone concentration of an experimentally simulated pollutant, by factors ranging from 100 to 800, was observed with the device* (called an airvest). With use of the airvest by the worker, the hood face velocity can be reduced, leading to substantial energy savings in conditioning of make up air in the building.

The airvest works by elimination or ventilation of the eddy that develops in front of a worker when the worker stands in the open face of a fume hood. Normally this eddy draws some of the pollutant (commonly generated near and in front of the worker) towards the worker's breathing zone.

Experiments using a heated full-size mannequin were conducted with a full-scale walk-in fume hood. Sulfur hexafluoride was used to simulate pollutant generation and exposure during a work situation. Flow visualization with smoke was also undertaken to evaluate the airvest qualitatively.

Key Words: Fume-Hoods, Exposure, Energy-efficiency, Pollutant-removal

*Patent pending

Reduced Worker Exposure and Improved Energy-efficiency in Industrial Fume-hoods using an Air Vest

ABSTRACT

Reduction in the breathing zone concentration of an experimentally simulated pollutant, by factors ranging from 100 to 800, was observed with the device* (called an airvest) described in this paper. If reduction in the worker exposure in not warranted, the hood face velocity can be reduced with the use of the airvest by the worker, leading to substantial energy savings in conditioning of make up air in the building.

The airvest works by elimination or ventilation of the back-eddy that develops in front of a worker when the worker stands in the open face of a fume hood. Normally this eddy draws some of the pollutant (commonly generated near and in front of the worker) towards the worker's breathing zone.

Experiments using a heated full-size mannequin were conducted with a full-scale walk-in fume hood. Sulfur hexafluoride was used to simulate pollutant generation and exposure during a work situation. Flow visualization with smoke was also undertaken to better understand the working of the airvest.

INTRODUCTION

Fume-hoods (also sometimes called spray-booths) are widely used in industry for removing airborne pollutants from localized production activity such as spray painting, washing work pieces in toxic solvent baths, or welding. Typically a fume hood consists of a rectangular shaped enclosure, with one open side. The opposite side consists of a bank of filter pads beyond which is positioned an exhaust fan. The aim of the fume hood is to protect workers from fumes or aerosol generated during the process.

Fume-hoods draw air over the process area, and exhaust it to the outside. Fume-hoods remove pollutants quite effectively when no worker is standing in the open face, partially blocking the air flow. However, when the air flow is partially blocked by a worker, an eddy develops in front of the worker that draws some of the harmful airborne pollutant (commonly generated near and in front of the worker) from the process area towards the worker's breathing zone. The presence of the eddy and it's deleterious effect on exhaust hood performance are well documented (e.g. Fuller and Etchells 1979, Malek et al. 1989, George et al. 1990).

---

*Patent pending

A. J. Gadgil and W. J. Fisk are Staff Scientists, and D. Faulkner is a Principal Research Associate, with the Indoor Environment Program, Lawrence Berkeley Laboratory, Berkeley, CA 94720.

An increase in the design face velocity to counter this effect, strengthens the eddy almost in proportion. Thus the expected improvement in pollutant removal is achieved at only a high energy cost, both in terms of fan power to the hood, and also for conditioning of the make up air supplied to the building that contains the hood. In addition, if air pollution abatement regulations require removal of pollutants from the exhaust stream of hoods (e.g. via a filter, adsorbent, or a system for condensing the volatiles in the exhaust gases), these processes will increase energy consumption almost in proportion to the hood exhaust flow rates. The energy costs associated with conditioning of the make up air and the pollutant removal processes can be reduced if a method is developed that allows exhaust hoods to operate efficiently (i.e. reduce the exposure of the worker without resorting to high volume flow rates).

Substantial reduction in the air flow without compromising the performance of the exhaust hood can be envisaged if a device can be designed that makes the worker essentially transparent to the flow of air into the exhaust hood. The proposed device, here called an "airvest", could be worn by the worker. It would draw air from the back of the worker, and expel it from the front. Under ideally matched flow conditions, the resulting air flow pattern behind and in front of the worker would be identical to that obtained without a worker blocking the flow. No back eddy would develop, and pollutant removal and transport would be as effective as that with an unobstructed exhaust hood. Under conditions of imperfect matching, the hood performance can be still expected to be improved because the airvest ventilates the region of the eddy.

In the subsequent sections we present results of tests of performance of airvests under a range of operating conditions and nominal hood face velocities, and present illustrative calculations estimating energy savings resulting from reduced need for make up air owing to the use of an airvest.

EXPERIMENTAL PROCEDURE

A full size walk-in industrial exhaust hood located at the Richmond Field Station was made available for the experiments by our colleagues at U.C. Berkeley. Two sets of experiments were undertaken. The first set consisted of visualizing airvest performance using smoke released in front of the worker. In the second set of experiments, a tracer gas technique was used to quantify pollutant exposures and pollutant removal efficiencies, with and without an airvest, at two hood flow rates.

The walk-in fume hood is a rectangular shaped metal enclosure open at one end. Air is drawn out of the hood through a filter bank at the opposite end. The worker stands in or near the open face, and undertakes a pollutant releasing activity (e.g. sprays paint on a work piece) inside the enclosure. The hood used in this work has face dimensions of seven feet (2.1 m) high and six feet (1.8 m) wide, and a depth (in the direction of air-flow) of six feet (1.8 m). Downstream of the filter bank which has dimensions of six feet by five feet (1.8 m by 1.5 m), is a manifold connected to a variable speed fan which exhausts to the outside.

The worker was simulated with a full size standing mannequin, positioned in the face plane of the hood. The mannequin was partly covered with electrical surface heaters (power output 75 W) to obtain a thermal plume similar to that from the body-heat of a worker. The simulated pollutant (smoke or tracer gas) was released at a point 41 in. (1 m) above the floor (which equals the height above the floor of the mannequin's elbow), and 7 in. (0.2 m) in front of the mannequin's stomach. With this release position, we intended to approximate the release point of the pollutant in a realistic situation.

Flow Visualization Experiments

In this series of experiments, the airvest was simulated inexpensively using two wooden boxes, each box about 4 in. (0.1 m) deep, and 12 in. by 12 in. (0.3 m by 0.3 m) on the sides. One box, mounted on the back of the mannequin, was equipped with four muffin (i.e. small propeller) fans, with intakes of the fans cut out on one of its square surfaces [Figure 1]. This intake box supplied air to an ejection box mounted on the mannequin's chest via two ducts (internal diameter 3 in. (0.08 m) each), one on each side of the mannequin, [Figure 2]. Air was expelled from the ejection box away from the mannequin's chest through a square pattern of 64 holes (diameter 13/64 in. (0.005 m)) [Figure 3]. Airvests used by actual workers would be designed so that they are more comfortable to wear and their performance would be optimized.

The copper tubing seen in the photographs was subsequently used for sampling tracer gas concentrations at various points; it was not used in the flow visualization experiments.

Smoke from an oil-based smoke generator was released at the pollutant release point described above. The impact of the slightly different buoyancy of the smoke on its flow pattern appeared to be negligible. The smoke patterns at two different hood face velocities, with and without the airvest operating, were photographed.

Tracer Gas Experiments

In the second set of experiments, sulfur hexafluoride (SF_6) was used as a tracer gas to quantify the pollutant concentrations at several points of interest at different hood face velocities, with and without airvest operation. In this set of experiments, the intake box mounted on the back of the mannequin was retained in place, but the fans were not operated. Instead, to allow a larger range of air flow rates, air was supplied to the ejection box (mounted on the mannequin's chest) with a stationary blower through a flexible duct (internal diameter about 3.5 in. (0.09 m)). The blower was placed on the floor in the face plane of the hood but outside the hood face. Air velocity in the center of the supply duct to the airvest was measured with a hot wire anemometer. Air velocities at the hood face (with the mannequin in place), and power consumption of the hood fan, were measured at different fan speed settings.

Each experiment was conducted as follows: Pure SF_6 was released at a rate of 0.08 L/minute at a point 41 in. (1 m) from the floor, and 7 in. (0.2 m) in front of the stomach of the mannequin. Air samples for measuring tracer gas concentrations were collected at the following points:

1. nose of the mannequin,
2. mouth of the mannequin,
3. 4.75 in. (0.12 m) in front of the mannequin's mouth,
4. 10 in. (0.25 m) in front of the mannequin's mouth,
5. 12 in. (0.30 m) behind the (disconnected) fans of the intake box,
6. 10 in. (0.25 m) in front of the mannequin's knees,
7. at the top edge of the center of the hood-face, and
8. at the center of the exhaust duct, downstream of the exhaust fan.

Samples from these points were collected at a constant rate during the test (for a duration of approximately 15 minutes), into gas sample bags. The concentrations of the tracer gas in each gas sample bag were subsequently analyzed using a gas chromatograph (GC) with an electron capture detector. The GC was calibrated using 11 calibration gases. The sampling technique time-averaged over the variations in concentration caused by unsteady flow, vortex shedding and turbulence associated with the back eddy.

MEASUREMENTS AND RESULTS

Hood Fan Power

For hood face velocities of 30, 56 and 118 feet per minute (fpm), (0.15, 0.29 and 0.60 m/s), the hood fan power consumption was 480, 575 and 950 W respectively. Here and throughout this paper, hood face velocities are reported in the presence of the mannequin at the hood face.

Flow Visualization Experiments

The power consumption of the muffin fans, mounted in the intake box of the airvest, was 14 W each. The air flow out of the front box of the airvest with these fans is estimated to be 13.5 cubic feet per minute (cfm) (6.4 L/s).

With the airvest switched off, the general pattern of airflow visualized with the smoke was observed to be similar to that described in the literature. Owing to the back eddy, the smoke lingers in the recirculating pocket of air (eddy) in front of the mannequin, frequently rising to the mannequin's breathing zone.

When operating the airvest, even though the air flow pattern is not identical to that without the mannequin, the smoke pattern changes significantly. The expelled air from the front of the mannequin now reduces (or eliminates) the back eddy, and consequently eliminates the smoke being drawn towards the mouth and nose of the mannequin.

Figures 4 and 5 show a matched pair of views, for hood face velocity of 95 fpm (0.48 m/s), with and without airvest operation. Figure 4 is with the airvest off, and Figure 5 with the airvest on. The significant reduction owing to airvest operation in flow of smoke into the breathing zone is visible in the photographs.

Tracer Gas Measurements of Pollutant Exposure

In the second set of experiments, the ejection box was supplied with air via a flex duct connected to a small blower. The flow rate was controlled by modifying, with a variac, the voltage supplied to the blower motor. The centerline air velocity in the flex duct was measured along with the power consumption of the blower, for two settings of the variac. At an air supply rate of 4.2 cfm (2.0 L/s) to the ejection box the blower consumed 12 W of power; at a supply rate of 40 cfm (19.0 L/s), the it consumed 170 W of power. For these initial experiments, we did not attempt to select an optimal (e.g. low power) blower, or reduce the resistance to air flow in the duct or the airvest.

The sampled concentrations of tracer gas are plotted as barcharts for six sets of experiments in Figures 6-11. Each bar represents the concentration of tracer gas in an air sample collected over 15 minutes. Figures 6-8 display results from experiments conducted with a hood face velocity of 56 fpm (0.28 m/s). The corresponding hood flow rate is approximately 2000 cfm (950 L/s). At this velocity the hood fan consumed 575 W. Tracer gas concentrations (in parts per billion or ppb) measured at various points are shown for airvest air supply rates of of 0, 4.2, and 40 cfm (0, 2.0, and 19.0 L/s) in Figures 6-8. The measured exhaust concentration declines slightly from about 1460 ppb to 1140 ppb as the air supply to the airvest increases from 0 to 40 cfm (0 to 19.0 L/s). Based on mass balance calculations, the tracer gas release rates, the hood flow rates, and the measured exhaust concentrations are mutually consistent, within experimental error.

The concentrations at the nose, mouth and and regions near the mouth are seen to decline dramatically with airvest operation. The tracer gas concentration at the nose declines from about 3800 ppb with the airvest non-operational, to 183 ppb with air supply rate to the airvest of 4.2 cfm (2.0 L/s), to 9 ppb at an air supply rate of 40 cfm (19.0 L/s). The concentration at the mouth similarly declines from 5850 ppb to 240 ppb to 7 ppb.

The results at the higher hood face velocity are somewhat similar. At a hood face velocity of 118 fpm (0.60 m/s) [hood fan power 950 W and hood flow rate of 4250 cfm (2000 L/s)], and with the airvest non-operational, the concentrations at the nose and the mouth of the mannequin are about 470 and 63 ppb, Figure 9. [Notice that, as expected, these concentrations are substantially lower than the corresponding concentrations at the lower hood face velocity of 56 fpm (0.28 m/s), Figure 6; however, operation of the hood with this higher face velocity does not reduce the breathing zone concentrations as substantially as operating the airvest does at the lower hood face velocity, Figure 8]. The airvest operation at air supply rate of 4.2 cfm (2.0 L/s) to the airvest is inadequate to significantly reduce the concentrations at the nose and mouth, (Figure 10), when the hood . This is probably owing to the poor matching between the large air velocity in the hood and the relatively small velocity of air ejected from the airvest. Such a mismatch would negate the operating principle of the airvest of keeping the airflow undisturbed by the presence of the mannequin. When the air supply rate to the airvest is increased to 40 cfm (19.0 L/s), Figure 11, a dramatic reduction in the concentrations at the mouth and nose takes place, to 3 ppb each, even lower than the values achieved with the airvest operation at the lower hood fan setting.

DISCUSSION

The tracer gas concentration at the nose with the hood face velocity of 56 fpm (0.28 m/s) and with the airvest on, was 52 times smaller than that with the highest hood face velocity of 118 fpm (0.60 m/s) and the airvest off. In addition, at the lower hood face velocity, the total direct energy consumption in the hood (including the fan power for the airvest) was 22% lower than that for the higher hood face velocity (745 W versus 950 W).

For certain air basins (e.g. Los Angeles), regulations are being discussed, or have been enacted, that require the air streams leaving industrial hood exhausts to be scrubbed of pollutants to maintain outdoor air quality. This is accomplished through filtering of the particulates, use of cyclones, condensing of volatiles (in the gas phase) on cold coils, or some other method of air cleaning. A decrease in the air throughput of the exhaust hood, possible with the use of airvests by workers, would then lead to additional savings in energy required for air cleaning. In addition, the size and cost of air cleaning equipment could be reduced.

More significant savings in energy use would often result from the decrease in the energy needed to condition the make up air entering the building housing the exhaust hood. The magnitude of these savings (in energy and dollar terms) is estimated for Chicago weather as an illustration:

A reduction in the hood face velocity from 200 fpm (1.0 m/s) to 100 fpm (0.5 m/s) in the fume hood used in this experiment reduces the fume hood air flow rate by about 4000 cfm (1900 L/s), and causes an equal reduction in the make up air requirement for the building housing the hood. Neglecting the difference between daytime and nighttime outdoor air temperatures, in Chicago weather (6000 heating degree days), this reduction in make up air for one shift (2200 hours/year) would lead to annual savings of about 152 MBtu (160 GJ) in delivered heating energy. Assuming gas fueled heating with a furnace efficiency of 75%, savings in input energy would be of 203 MBtu (213 GJ). At a gas price of $6/MBtu, this equals annual savings of $1200. Savings would be proportionately larger for multiple shift industries, and vary according to the local heating degree days.

The results described in this paper focus on the two successful designs: a fan powered airvest with an air intake on the back and supplied power with a flexible electrical cable, and a "passive" airvest with only an air ejector on the front, supplied air through a 3.5 in. (0.09 m) diameter flexible hose.

The fan powered airvest design with an electrical cable (which could be a low-voltage one) appears attractive because it would interfere less with the mobility of the worker, than would the "passive" airvest that must be supplied air with an external air hose. Furthermore, the prototype fan powered airvest used muffin fans which are not well suited for pumping air against significant back pressure that develops in the airvest. As a result, smaller power consumption, and better performance would be possible with an improved design and appropriate fan selection.

An earlier airvest design, fabricated with side intakes and the muffin fans placed directly on the front ejector surface, was unsuccessful. The fans introduced enough swirl in the outgoing air stream that the increased turbulent diffusion of the pollutant owing to the swirl was larger than the effect of reducing the back eddy. Thus it appears that a manifold of some sort in the front is necessary.

CONCLUSIONS

The airvests tested in this project were very rough prototypes. However, they have demonstrated the proof of the concept, as intended in the project objective. Reduction by factors ranging from 100 to 800 in the breathing zone concentration of a simulated pollutant was observed with the use of an airvest on a heated mannequin in a full sized fume hood. Airvests could therefore be useful in meeting the declining limits on acceptable worker exposure to various industrial pollutants.

The experiments demonstrate that it is possible to reduce worker exposure to pollutants in the breathing zone by about a factor of 50, while concurrently reducing the direct energy consumption in the fume hood. Large savings in indirect energy (used in the building to condition the make up air) are also estimated to result from the use of airvest concurrent with a reduction in the hood face velocity. The savings are estimated to be about $1000 per hood per shift in Chicago weather; actual savings would vary according to the local climate, and in proportion to the number of shifts.

Reduction in the bulkiness and power consumption of the airvest designs described here appears possible with additional work. Further investigation should address issues such as the shape of the front manifold (to make it less bulky), the position of air-intakes, the method of supplying air to the airvest, and airvest performance in field settings with real workers. For this purpose, collaboration with industry would be desirable. The future research effort should also address the possibility of failure modes of the airvest (e.g. pollutant exposure at different orientations of the airvest to the hood air flow, and for different release points and release velocities of the pollutants than those investigated here).

ACKNOWLEDGEMENTS

Participation in the conduct of experiments by Douglas Sullivan is gratefully acknowledged. We thank Dr. Michael Yost and Professor Catherine Koshland, both of U.C. Berkeley, for arranging and allowing access to the full size industrial flow hood at the Richmond Field Station (RFS) for the experimental measurements. We also thank the staff of the SEEHRL Facility of the RFS for their cooperation.

This research was partly supported by the California Institute for Energy Efficiency through grant No. BG 90-225, by the Assistant Secretary for Conservation and Renewable Energy, Office of Building Technologies, Building Systems Division of the US Department of Energy under Contract DE-AC03-76SF00098, and by a U.C. Berkeley Faculty Research Funds Award to Professor A. H. Rosenfeld.

REFERENCES

Fuller, F. H.; and A. W. Etchells 1979. The rating of laboratory hood performance. *ASHRAE Journal,* October 1979, Vol. 21, No. 10, p. 49-53.

George, D. K.; M. R. Flynn; and R. Goodman 1990. The impact of boundary layer separation on local exhaust design and worker exposure. *Applied Occupational and Environmental Hygiene,* August 1990, Vol. 5, No. 8, pp. 501-509.

Malek, R. F.; J. M. Daisey; and B. S. Cohen 1989. Investigation of breathing zone concentration variations: the effect of air flow patterns into a spray-booth hood. Presented at American Industrial Hygiene Conference, St. Louis, Missouri, May 21-26, 1989.

Figure Captions

Figure 1	A rear view of the mannequin placed in the hood face plane showing the intake box mounted on its back, and one of the two ducts leading to the ejection box in the front. The filter bank at the other end of the hood is also visible in the photograph.
Figure 2	A side view of the mannequin. Note the intake and ejection box hung with straps from its neck. Black heater foils are taped to its legs, thighs, arms, and waist. The band on its head is also a heater. The heaters are used to create a thermal plume similar to that from the body heat of a worker. Note the copper tubing at the mannequin's nose, mouth, and 4.5 and 10 in. in front of its mouth, used for sampling tracer concentrations in the breathing zone.
Figure 3	A front view of the mannequin, showing the ejection box and the ducts leading into it.
Figure 4-5	A pair of matched views, the first showing the smoke trapped in the recirculating eddy in front of the mannequin rising to its breathing zone (photograph 4), and the second showing the smoke being effectively removed with the operation of the air-vest (photograph 5). The hood face velocity is 95 fpm (0.48 m/s), air supply rate to the ejection box is 13.5 cfm (6.37 L/s).
Figure 6-8	Barcharts of measured concentrations of SF_6 at various points, with the hood face velocity of 56 fpm (0.28 m/s), and air ejection rates from the airvest of 0, 4.2, and 40 cfm (0, 2.0, and 19.0 L/s). The measurements are averaged concentrations of SF_6 over 15 minute intervals. Pure SF_6, to simulate a pollutant, was released at a rate of 0.08 L/minute, at the mannequin's elbow height 7 in. (0.2 m) in front of its stomach. Words at the bottom of each column in the barcharts describe the locations of the respective sampling points; the locations are described in more detail in the text.
Figure 9-11	Barcharts of measured concentrations of SF_6 at various points, with the hood face velocity of 118 fpm (0.60 m/s), and air ejection rates from the airvest of 0, 4.2, and 40 cfm (0, 2.0, and 19.0 L/s). The measurements are averaged concentrations of SF_6 over 15 minute intervals. The SF_6 release rate and location were same as those described above.

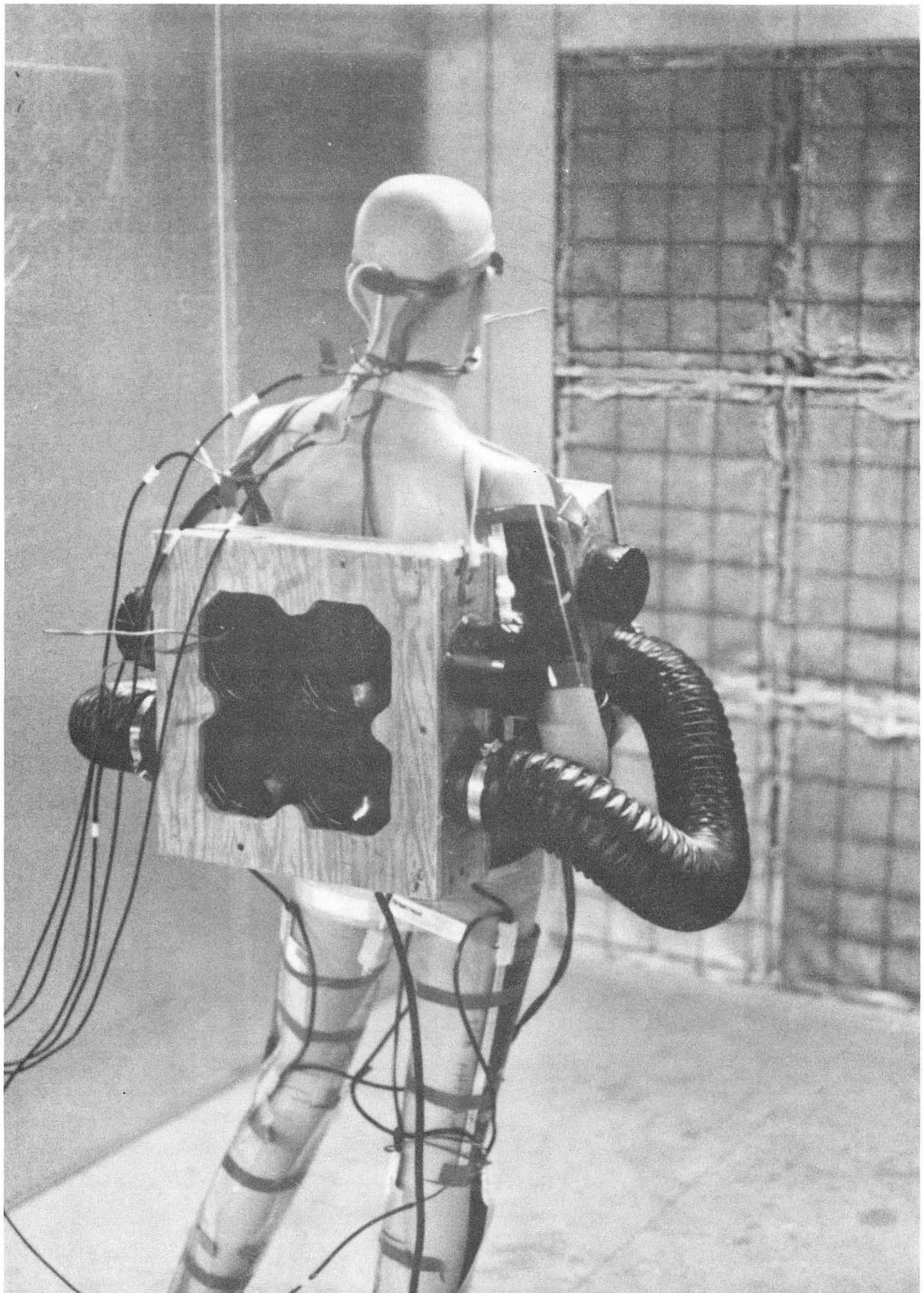


Figure 1

Figure 2

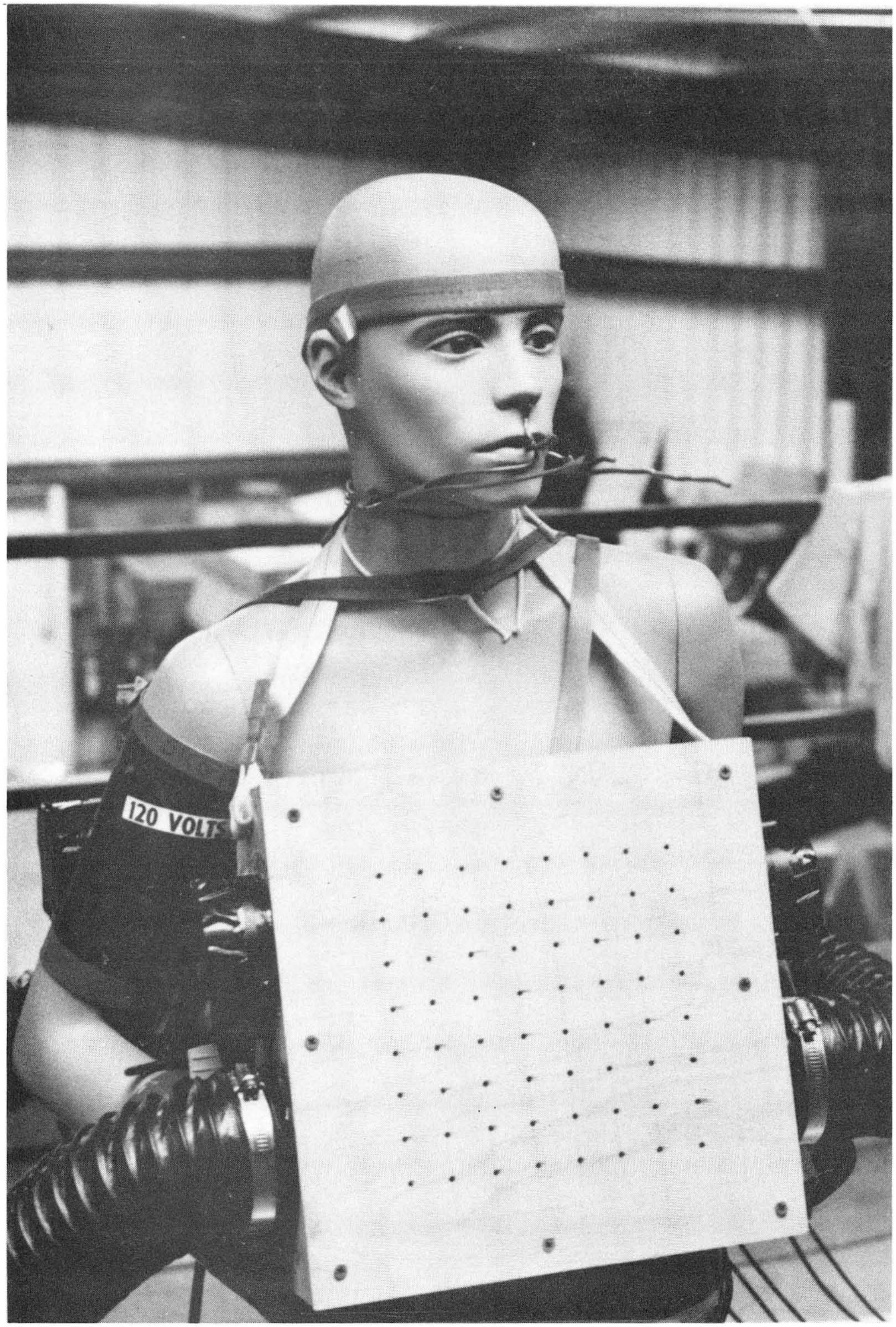


Figure 3

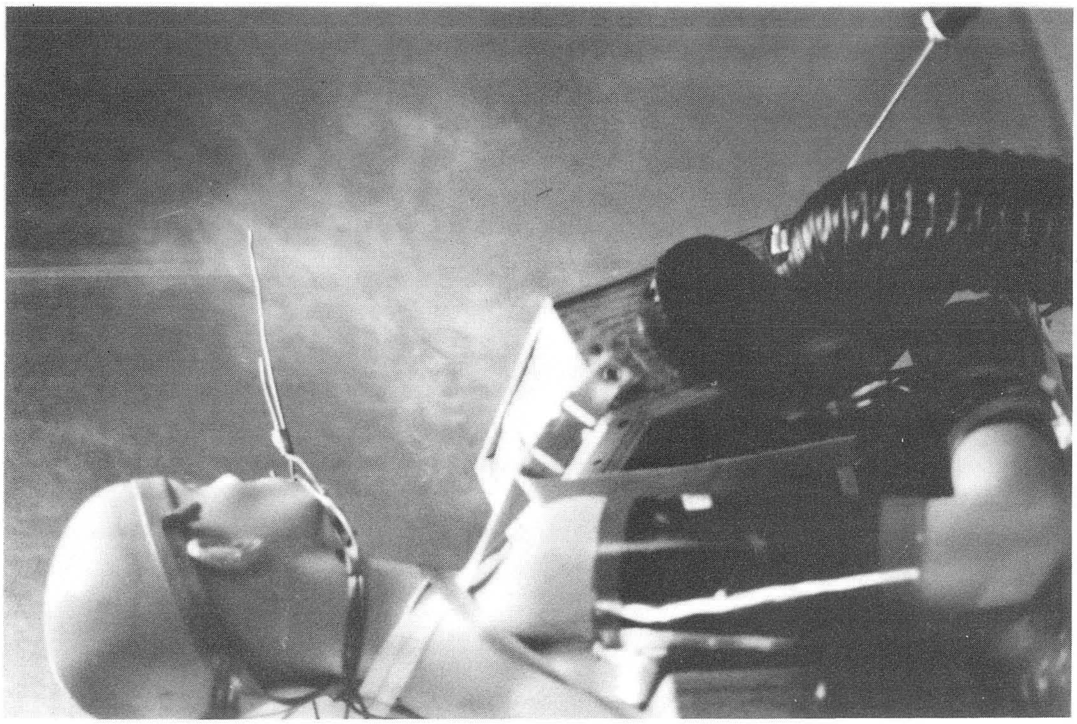


Figure 4

Figure 5

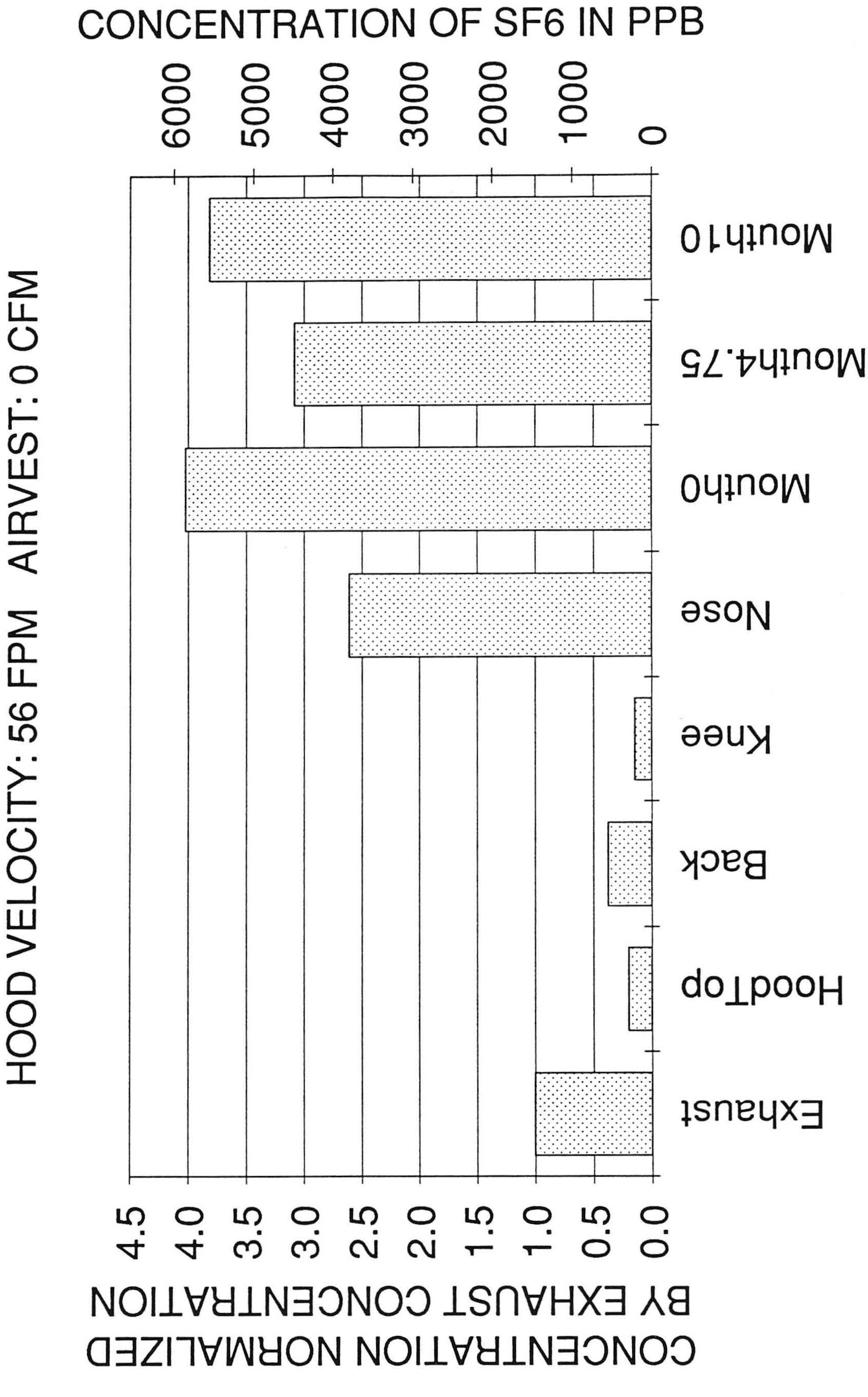
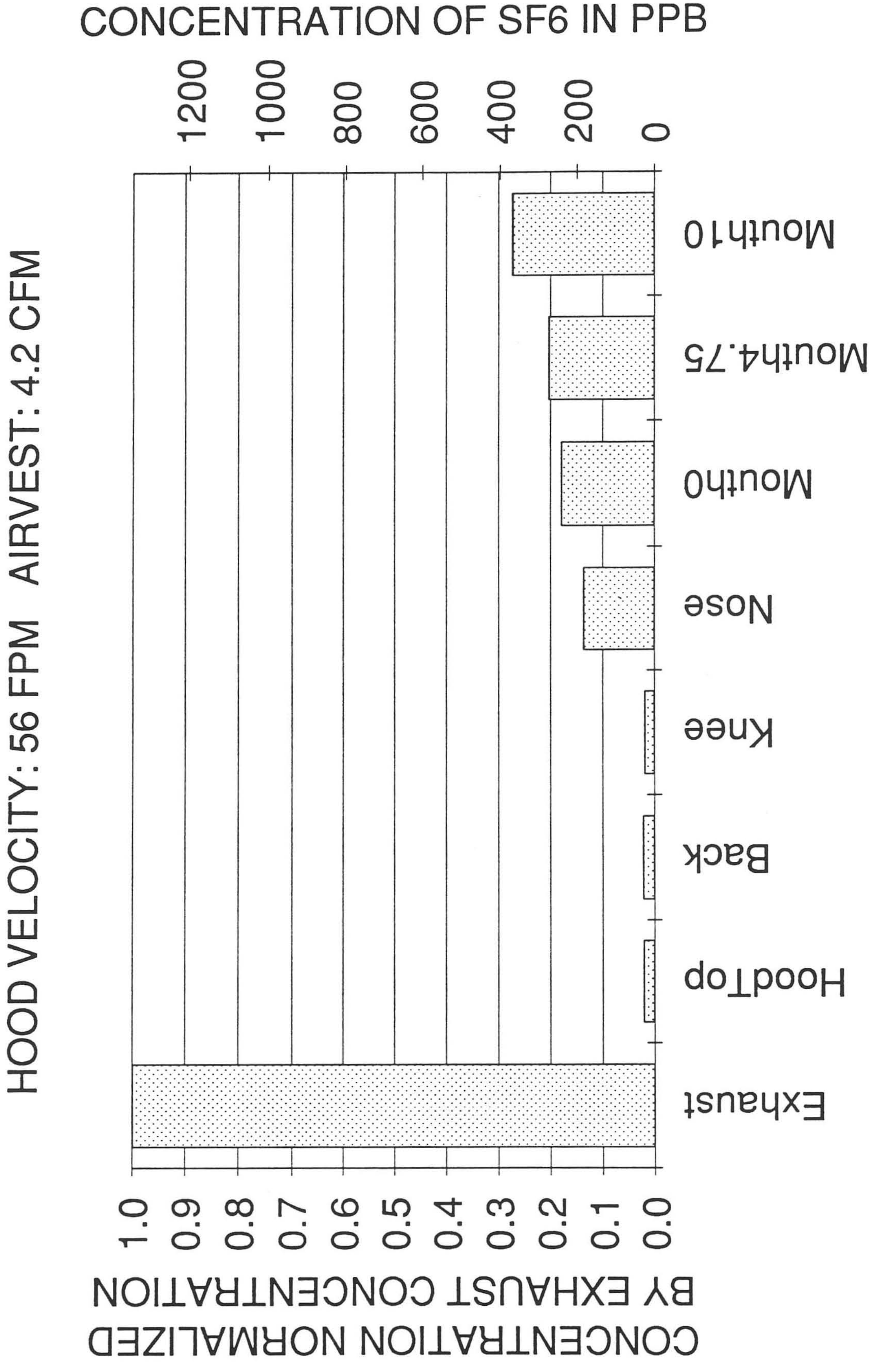

HOOD VELOCITY: 56 FPM AIRVEST: 0 CFM
CONCENTRATION OF SF6 IN PPB
6000
5000
4000
3000
2000
1000
0
CONCENTRATION NORMALIZED BY EXHAUST CONCENTRATION
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Mouth10
Mouth4.75
Mouth0
Nose
Knee
Back
HoodTop
Exhaust

Figure 6



HOOD VELOCITY: 56 FPM AIRVEST: 4.2 CFM
CONCENTRATION OF SF6 IN PPB
1200
1000
800
600
400
200
0
Mouth10
Mouth4.75
Mouth0
Nose
Knee
Back
HoodTop
Exhaust
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
CONCENTRATION NORMALIZED BY EXHAUST CONCENTRATION

Figure 7

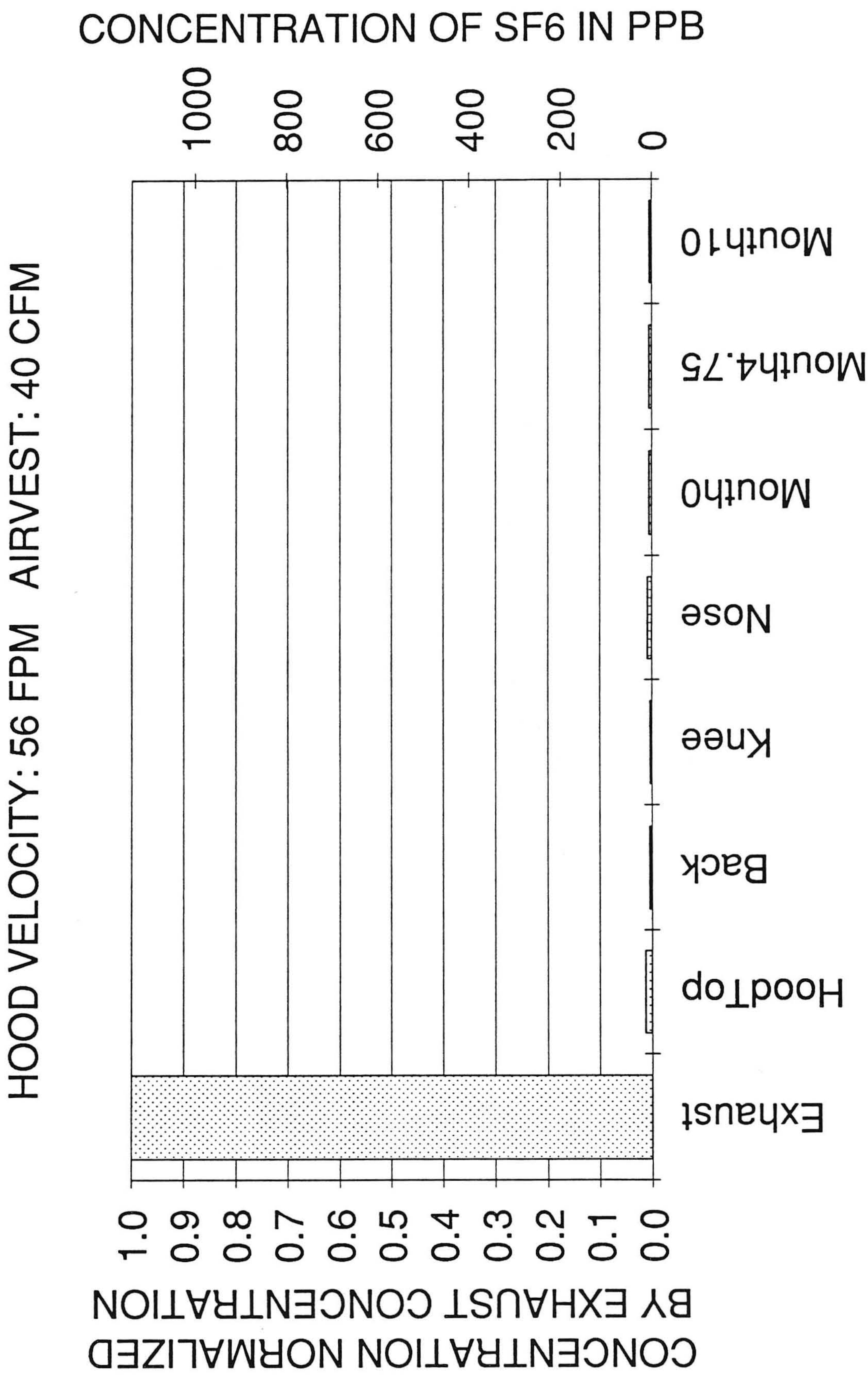

HOOD VELOCITY: 56 FPM AIRVEST: 40 CFM
CONCENTRATION OF SF6 IN PPB
1000
800
600
400
200
0
Mouth10
Mouth4.75
Mouth0
Nose
Knee
Back
HoodTop
Exhaust
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
CONCENTRATION NORMALIZED
BY EXHAUST CONCENTRATION

Figure 8

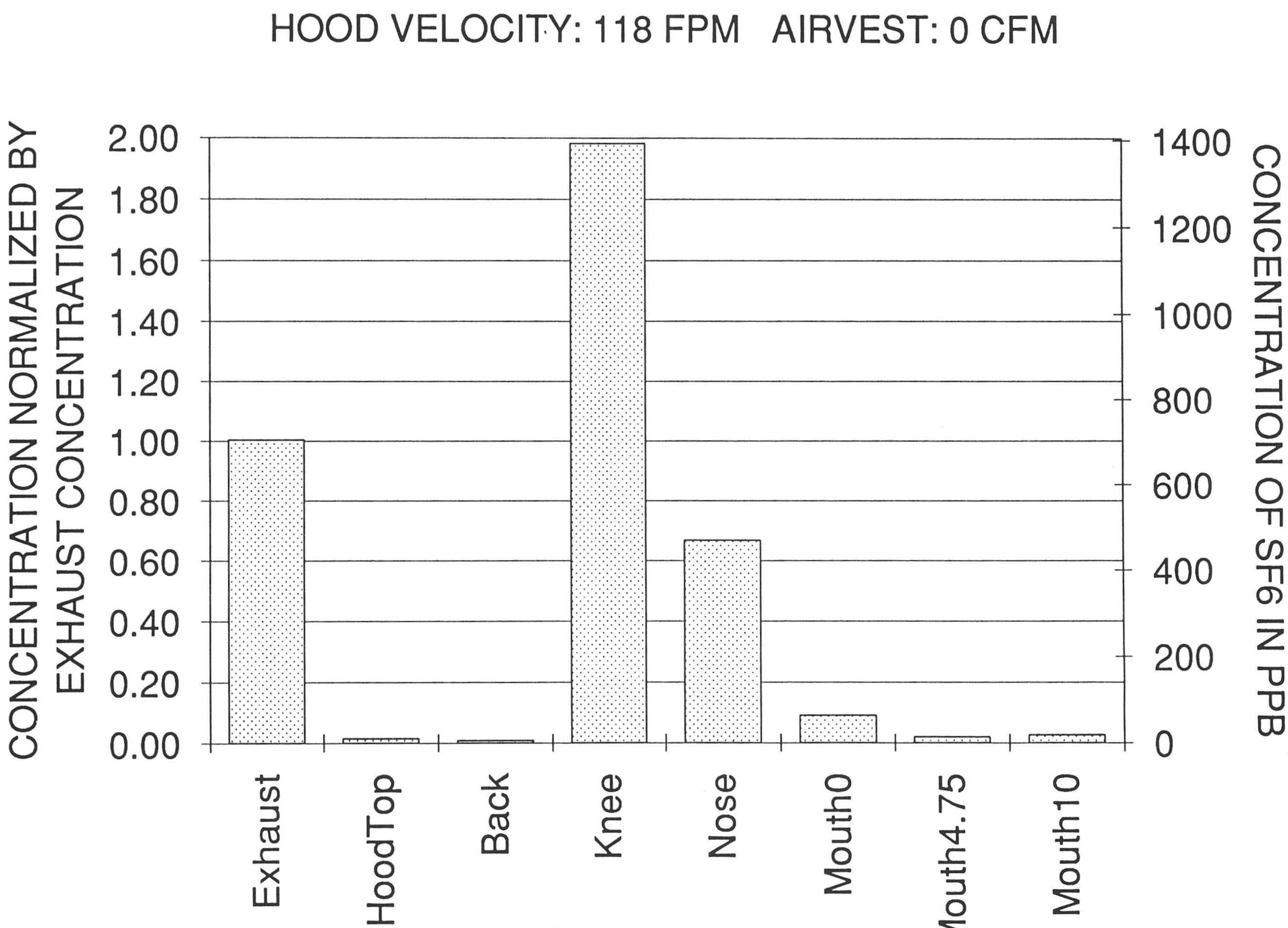

HOOD VELOCITY: 118 FPM AIRVEST: 0 CFM
CONCENTRATION NORMALIZED BY EXHAUST CONCENTRATION
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
CONCENTRATION OF SF6 IN PPB
1400
1200
1000
800
600
400
200
0
Exhaust
HoodTop
Back
Knee
Nose
Mouth0
Mouth4.75
Mouth10

Figure 9

HOOD VELOCITY: 118 FPM   AIRVEST: 4.2 CFM

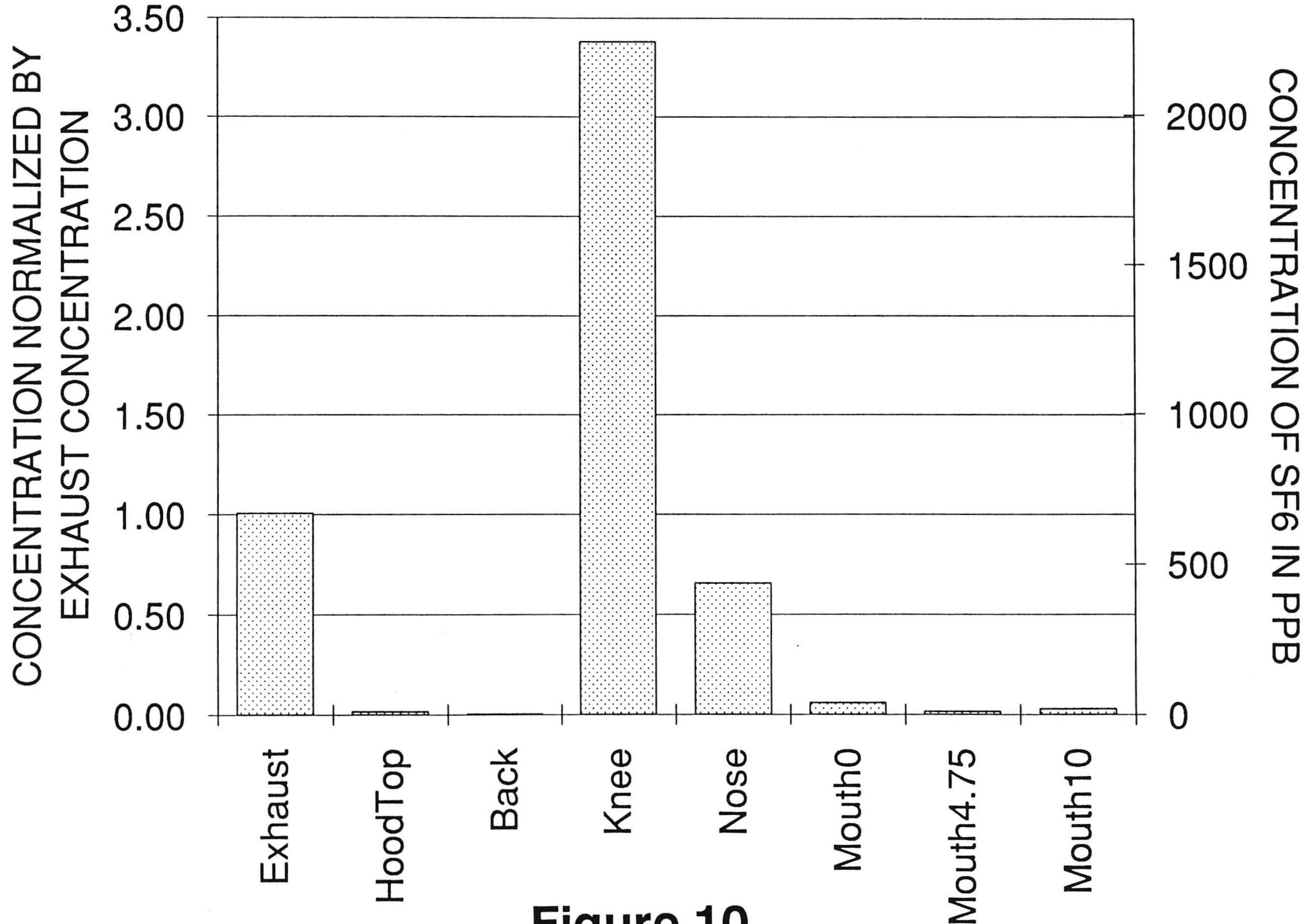


Figure 10

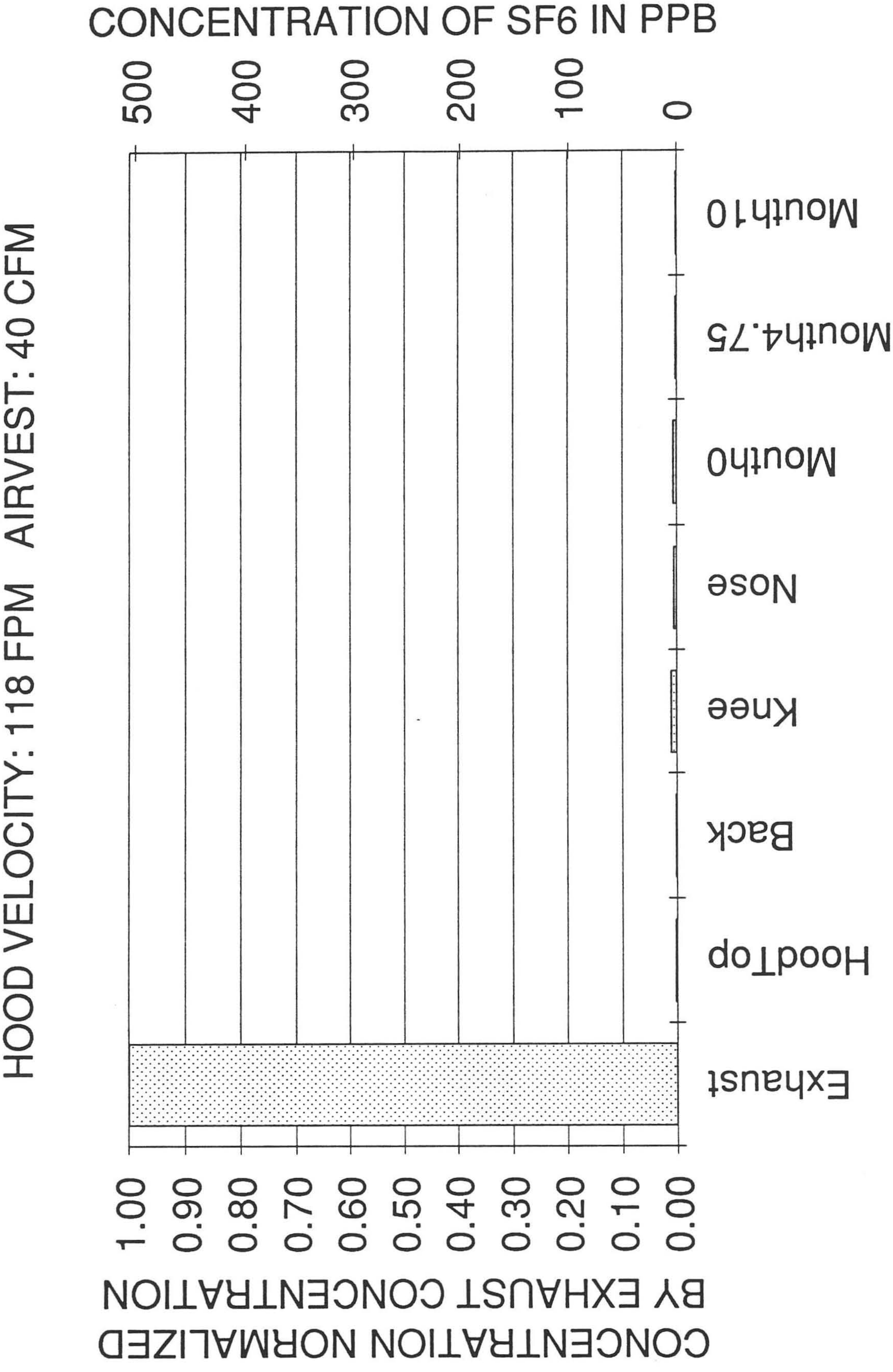

HOOD VELOCITY: 118 FPM   AIRVEST: 40 CFM
CONCENTRATION OF SF6 IN PPB
500
400
300
200
100
0
Mouth10
Mouth4.75
Mouth0
Nose
Knee
Back
HoodTop
Exhaust
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
CONCENTRATION NORMALIZED
BY EXHAUST CONCENTRATION

Figure 11

LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
TECHNICAL INFORMATION DEPARTMENT
BERKELEY, CALIFORNIA 94720