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# EXPERIMENTAL DESIGN AND INSTRUMENTATION FOR A FIELD EXPERIMENT

## FINAL REPORT

Vernon A. Benignus[1] and Milan J. Hazucha[2]

March 1992

Supported by

U.S. ARMY BIOMEDICAL RESEARCH AND DEVELOPMENT LABORATORY
Fort Detrick, Frederick, MD 21702-5012

Project order 1812

[1]U.S. Environmental Protection Agency
Human Studies Division
Clinical Research Branch
Research Triangle Park, NC 27711

AND

Department of Psychology
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This report concerns the design of a field experiment for a military setting in which the effects of carbon monoxide on neurobehavioral variables are to be studied. A field experiment is distinguished from a survey by the fact that independent variables are manipulated, just as in the laboratory. Thus causal relationships may be discovered rather than correlations.

It was proposed to study the effects of multiple levels of CO exposure on compensatory tracking (main gun pointing at a target in a tank), electroencephalogram spectra and speech discrimination. Factors which govern the experimental design were considered in detail. Statistical and control matters were discussed.

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**ABSTRACT CONTINUED**

Many measurements which were proposed required special instrumentation. The control of the experiment and the acquisition of data required the interconnection of the special instrumentation with equipment at Aberdeen Proving Ground. The present report documents the development and/or testing of some of the special equipment (EEG helmet, facemask, control and data acquisition system) and specifies how it is to be connected to the other equipment to make a working system.

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## TABLE OF CONTENTS

## EXECUTIVE SUMMARY

This document is a report of a research planning effort and associated instrumentation development. The objective of the planned research was to conduct a field experiment with realistic scenarios, military personnel and an armored vehicle such as a tank. The purpose of the field experiment was to determine the role of carbon monoxide (CO) exposure in a tank atmosphere on actual military performance as opposed to laboratory task performance. Special instrumentation and equipment performance data were needed in the projected experiment. The design and evaluation of the instruments was part of the planning project.

## CHAPTER 1. DESIGN AND PLANNING OF A FIELD EXPERIMENT

The term "field experiment" was defined to mean a study in which the independent variables were manipulated just as they would have been in a laboratory study as compared to a study in which observations were only collected from an ongoing field exercise. In the latter case only correlations, not causes, could be identified. The neurobehavioral dependent variables recommended for study were (a) compensatory tracking (b) electroencephalogram (EEG) spectra and (c) speech discrimination. The independent variable was recommended to be the level of CO in the inhaled air of the crewman. The commander and the gunner were to be subjects.

Compensatory tracking performance was to be measured as the ability of the gunner to maintain pointing of the main gun on a horizontally moving target. The target was to move back and forth in a pseudo-random manner. The task was to be performed under several atmospheric CO levels. The score was to be computed as the mean absolute angular distance of the gun off target as measured over several trials.

The EEG was to be measured as a two-channel signal between left and right occipital and parietal sites. Spectra were to be computed and used as the dependent variable. Comparisons were to be made across different CO exposure conditions. The interpretation of spectral changes were to be in terms of activation of the EEG.

Speech discrimination was to be measured in a way analogous to the test of Speech Perception in Noise (SPIN). A special version of SPIN was to be constructed so that words and sentences of military relevance would be used instead of the more artificial material of the original test. The noise to be used was to be typical of tank sounds.

The above experiment would require extensive instrumentation to perform. Many of the devices would have to be specially designed and constructed. The remainder of the equipment exists at Aberdeen Proving Grounds (APG), Maryland, and could be adapted to the experiment. Much of the task was the specification of the interconnections between the various electronic systems. The remaining chapters all concern some aspect of instrumentation.

## CHAPTER 2. EEG HELMET DESIGN, CONSTRUCTION AND TESTING

It was necessary to devise a way to collect EEG signals in a military environment. Such signals may be disrupted by movement of the test subject and touching of the electrodes on the test subjects scalp. A system was designed, constructed and tested.

The electrodes and low-noise wires were applied to the subject's scalp with collodion, a skin glue, to keep them from moving. Instead of connecting the electrode wires to an input connector on, e.g., the subject's chair, the wires were connected to a specially-constructed radio frequency (RF) telemetry unit mounted in a modified helmet which was worn by the subject. The EEG signal was then transmitted to a telemetry receiver which was to be mounted inside the test vehicle.

Tests demonstrated that the signals were faithfully and reliably reproduced by the new EEG helmet. Tests of susceptibility to interference by subject head motion demonstrated that the unit was substantially more noise immune than traditional methods. Further tests demonstrated that most of the noise immunity was due to the short signal paths and RF transmission system than to the use of low-noise wires.

## CHAPTER 3. FACEMASK EVALUATION EXPERIMENT

The atmosphere to be breathed by the subjects was to be delivered by a facemask and valving system. It would be important to know that the mask (a) leaked minimally and (b) did not appreciably affect the tasks to be performed. It was decided to evaluate commercially-available facemasks for such parameters.

Three masks were selected by reviewing specifications of many products. Leakage was measured by appearance of a tracer gas (helium) in the exhaled air of subjects wearing the mask. It was shown that each of the masks leaked drastically under some circumstances. When a drastic leak was not present, the leakage was minimal and did not appreciably differ among masks. No difference in the size or frequency of drastic leakage was discovered among the three masks. It was concluded that masks are a poor way to deliver well-metered doses of inhaled gas.

**CHAPTER 4. CONTROL AND DATA ACQUISITION SYSTEM (CDAS) DESIGN, CONSTRUCTION AND SPECIFICATION**

A general purpose (CDAS) was designed, constructed and tested. The system was microprocessor based and achieved functional flexibility by programming all events in Fortran. Hardware flexibility was achieved by making all wiring connections via a patch panel. In this way no piece of hardware was dedicated or permanently connected to any other. The input and output for the microprocessor was via hardware interfaces. The system is specified in the chapter.

**CHAPTER 5. MEASUREMENT AND CONTROL HARDWARE**

This chapter concerns the conceptual interconnections between the CDAS, the specially-constructed hardware and the APG equipment. No wiring diagrams or detailed specifications are given because these depend on the equipment to be selected at the time of the experiment. The purpose is to show the general instrumentation plan.

## LIST OF FIGURES

## LIST OF TABLES

## TABLE OF ABBREVIATIONS

| | |
|---|---|
| CDAS | Control and data acquisition system. |
| CNS | Central nervous system. |
| CO | Carbon monoxide, an invisible, odorless gas which is the product of incomplete combustion. |
| COHb | Carboxyhemoglobin, a measure of the level of carbon monoxide in the blood. |
| df | Degrees of freedom associated with a statistical test. |
| ECG | Electrocardiogram, a small electrical voltage emitted by the heart. |
| EEG | Electroencephalogram, a small electrical voltage emitted by the brain which varies as a function of time. |
| p | Probability of an event or outcome of a test of statistical significance. |
| PPM | Parts per million. |
| r | Correlation coefficient (Pearson's product-moment). |
| SPIN | Speech perception in noise, a standardized test. |
| t | Student's t, a statistical test for significance. |
| $T^2$ | Hotelling's $T^2$, a multivariate statistical test of significance. |

# CHAPTER 1

# DESIGN AND PLANNING OF A FIELD EXPERIMENT

# CHAPTER 1

# DESIGN AND PLANNING OF A FIELD EXPERIMENT

## INTRODUCTION

### DEFINITION

As used in this document, the phrase "field experiment" has a special meaning. In a classical field study, the observer or scientist simply records and measures variables. In a classical laboratory experiment, the scientist manipulates independent variables and measures the effects of the manipulations on dependent variables. The variables are designed to be "representative" of the field situation and tasks, but are only approximations or fractional parts of actual field tasks and situations. In the field study, only correlations can be performed, but no causal statements can be made from the results (Kleinbaum, Kupper & Muller, 1988, Ch. 4). In a laboratory experiment causal statements can be made, but the variables have usually been simplified to the point that the generality of the result is legitimately open to question (Chapanis, 1967). A "field experiment" is defined in this document as an experiment involving classical manipulation of dependent variables and measurement of independent variables but in the full complexity of a field setting. The objective of a field experiment is to be able to make causal statements about results which have better generality and are good approximations to actual military situations.

PURPOSE OF EXPERIMENT

The field experiment was to be the last part of a series of laboratory experiments on the effects of CO exposure on task performance. The plan was to document the effects of CO exposure in the well-controlled, simple laboratory setting. Measurement techniques for a sensitive dependent variable were to be devised. When a stable experimental laboratory protocol had been worked out in which the effects of CO exposure on behavior could be consistently demonstrated, the protocol was to be used in a field experiment. If the laboratory tasks were representative of the field performance and if the myriad other independent variables had a sufficiently small effect, then the CO effect should have been measurable in the field experiment.

The dependent variable which, at the time of the beginning of the present planning effort, seemed to hold the most promise for a stable effect of CO was compensatory tracking. The variable had been detrimentally affected by CO exposure in several studies (Putz, Johnson & Setzer, 1976, 1979; Benignus, Muller, Barton & Prah, 1987). While the planning for the field experiment was in progress, however, research on compensatory tracking failed to consistently demonstrate any CO effects (Benignus, Muller, Smith, Pieper & Prah, 1989).

Another variable which promised to be sensitive was the electroencephalogram (EEG). The EEG and its spectrum have been used to describe the general state of activation of the central nervous system. When the present planning effort commenced, it was decided to include EEG measurements in the protocol. Extensive testing in a number of experiments revealed, however, that the EEG spectrum was not affected by any tested level of COHb (Benignus, Muller, Kafer, Pieper & Smith, 1987).

A third variable which was to be measured in the field experiment was speech discrimination (Lewis, Benignus Muller, Malott & Barton, 1988). The logic for inclusion of this variable is that in a noisy environment, the performance of speech discrimination is marginal at best. Even in a quiet environment the task involves extensive central nervous system processing. If any additional CO-induced decrement were to be encountered, the effect could be noticeable and important.

If CO effects on task performance could not be reliably demonstrated in a well-controlled laboratory experiment, it is very unlikely that such effects could be demonstrated in the field experiment. It was therefore recommended that, at least until a stable laboratory effect of CO could be demonstrated, the rather expensive field experiment should not be performed. Planning was begun for a field experiment before the above results were obtained and it was determined that the variables were not reliably affected by CO. The field experiment was to be ready to perform as soon as the laboratory work ended.

Even though the field experiment is not actually being planned in the foreseeable future, documentation of the planning is presented here. The principles of the experimental may be useful in other contexts. The instrumentation design, implementation and evaluation may also be useful in other work.

An experimental design was to be delivered. Implementation of the experiment and medical and safety issues were to be the responsibility of the Army.

## EXPERIMENTAL DESIGN

### SUBJECTS

To make the experiment as representative of the field situation as possible, subjects were to be trained tank crewmen. It would be desirable for the crews to be composed of men who were members of an existing crew, so that they were already accustomed to working together as they would be in the field. The latter may not be possible if one or more crew members does not meet health requirements for participation as determined by the medical staff who actually supervise the experiment. At the present time, more characteristics of the subjects cannot be given.

### INDEPENDENT VARIABLES

The atmosphere inhaled by the subjects is the independent variable of interest. Three conditions were to be studied; (1) a non-polluted control atmosphere (2) an atmosphere containing CO pollution only and (3) an atmosphere containing all of the pollutants typically found in a tank during a firing exercise. In condition 2 the temporal profile of the CO was to be typical of the CO-component profile of the tank atmosphere during a firing exercise. Pollutants in condition 3 are delivered via facemask to keep the condition comparable to the other two.

The logic for selection of the above conditions of exposure is that the pure CO effect could be tested by comparison of the performance of the control group and the CO- only group. The effect of the typical tank atmosphere with all pollutants can be found by comparison of groups 1 and 3. Finally a test can be made of the hypothesis that CO is the only pollutant in the typical tank atmosphere which affects performance by comparison of the scores of groups 2 and 3.

Delivery of atmospheres to be inhaled by the subject was to be via facemask. Although not always worn, facemasks do not represent a condition which is atypical of tank crew performance. Thus, while the crewman's performance would be affected by the presence of a facemask, the effect would be strictly generalizable to other performance with a facemask. It is also likely that the facemask would simply subtract a constant from each group's performance score and thus not be synergistic with the pollutants.

The concentration of the pollutants in the inhaled atmosphere would vary over time. A typical exercise scenario should be selected for the vehicle and ordinance being fired. As the rounds are fired, the pollution would build up in a loosely stepwise fashion. It is possible, therefore, that the concentration-effects function for the pollutants can be determined, since the effect of time-on-task will be accounted for in the control group. Only the possible synergism between time-on-task and pollutant would be confounded.

Depending on the concentration of the pollutants due to the firing exercise, it may be desirable to perform the exercise without ventilation in the tank. This is a condition under which tanks must sometimes operate and so would provide good generality. The latter might be desirable to produce pollutants in the upper regions of the desired concentration-effects function without excessively long exercises or excessive numbers of rounds being fired. It would be important to consult with appropriate military personnel on the design of the firing scenario to assure that what was being planned was a good approximation of actual scenarios.

**CONTROL VARIABLES**

A number of variables in a tank can affect the crewman's performance other than the atmospheric pollution. Among them are temperature/humidity, noise/vibration and individual skill differences. Unless such variables are accounted for, the variances of the data are likely to be high.

**Meteorological.** The tank internal temperature and humidity are functions of the outside meteorological conditions and the heat generated by the internal machinery, e.g. the engine and the firing of rounds. The body heat and humidity from personnel also contribute. Among the above contributors to the determination of the inside temperature and humidity, the internal machinery and personnel contributions would be matched across groups. The outside temperature and humidity are not easily brought under control, however.

Another meteorological variable of concern is the wind speed. Wind speeds of greater than 5 m/sec have the potential of affecting the pollutant concentration inside the testing vehicle. Under one condition of the proposed experiment, the actual internal vehicle atmosphere is to be breathed. When this condition is in effect, the wind speed is of concern.

To minimize meteorological contributions perturbations, it is possible to proceed in one of two ways. Temperature, humidity or wind limits could be decided, so that the experiment would simply not be conducted unless the conditions were within bounds. The other alternative is to measure conditions and then use covariance analysis to mathematically account for effects. The former method is probably too cumbersome and would result in too many canceled experiments. The use of covariance analysis is also advantageous in that it allows for a more representative experiment. The disadvantages of covariance analysis is that more subjects are required in the experiment to allow for the degrees of freedom lost in estimation of the covariance. Account of the latter must be made when the actual number of subjects are selected by an appropriate power analysis.

It is important to recognize that in the experimental design, heat and humidity will covary with the pollution. Thus if behavioral differences between groups eventuate, it will not be possible to separate the contribution of the temperature and humidity from the pollution effects. It may be possible to estimate the contributions by simulation if covariance analysis is used. The confidence of a simulation would rest on, among other things, the ranges of temperature and humidity which actually occurred at each stage of the exercise. In any event, the correlation of temperature and humidity with the duration of firing and the pollution is typical of the non-experimental situation and is therefore representative.

__Noise/vibration.__ Performance of many tasks is affected by environmental noise/vibration. It is therefore important to the representative design of the study, to assure that the noises and vibration inside the tank be typical of some firing scenario.

The experimental protocol will assure that the noise and vibration factors are controlled across groups. As with temperature and humidity, the cumulative effects of noise and vibration on performance cannot be separated from the pollution effects since they are correlated.

__Skill Differences.__ The skill of crewmen varies as a function of the individual and as a function of the occasion of measurement. One of the classical ways to control for differences among individuals is to test each subject in all conditions. Such a repeated-measures design has consequences in terms of statistical analyses, but if individual differences are large the procedure is sometimes warranted (Hays, 1963, Ch. 13). Whether each subject is to be tested in all conditions or a separate group of subjects is tested in each condition must depend on the expected individual differences, the power of the experimental design and the overall number of subjects available as compared to the time each subject can spend being tested. Such things cannot be known until there are more data about performance effects and until the other logistics of an experiment have been worked out.

Variation in skill within a particular subject over time, e.g. between testing sessions or over the course of days, can also be controlled by use of a baseline procedure. In this context, the behavioral performance should be measured in each subject before the exposure to the atmospheric condition begins. After baseline measurement, the exposure begins and the performance is to be measured during exposure. During analysis, the baseline performance can be used as a standard for each subject on that day. Analysis of covariance, with the baseline scores as the covariate, can be then used to account for individual and temporal variation in skill. The procedure is analogous to analyzing all scores as percent of baseline or change from baseline. The latter two procedures work well under restrictive circumstances but the analysis of covariance has greater generality and fewer assumptions (Kleinbaum, Kupper & Muller, 1988, Ch. 15).

Since the baseline measurement technique statistically controls for both individual and temporal variation in skill, it is a good general alternative to testing each subject in all conditions. Even if each subject were to be tested in all conditions, the baseline measurement should be used to control for temporal variation within subjects.

In the present case, there are already repeated measures over time for each subject, within each exposure condition. It would probably strain the statistical assumptions of repeated measures analysis of variance to also test each subject in each exposure condition. It is therefore proposed that each of the three exposure groups be composed of an independent group of subjects and that baseline measurement be used with analysis of covariance to account for individual and temporal variation in skill.

**DEPENDENT VARIABLES**

The original plan was to measure three groups of behavioral variables; (1) tracking (2) EEG spectra and (3) speech discrimination. A priori hypotheses were to be made about the first two and the speech discrimination was to be analyzed on an exploratory basis (Muller, Barton & Benignus, 1984).

__Tracking__. As discussed in the introduction, compensatory tracking was considered the most promising dependent variable in terms of sensitivity to disruption by CO exposure. This variable has a close analog in tank crew performance. The tracking of the target by the main gun, just prior to firing is an example of pursuit tracking. In the laboratory, the target was presented on a CRT screen and the control mechanism was a joystick. The subject's task was to compensate for the target's tendency to move (driven by a pseudorandom function), thereby holding the target stable in the center of the screen. In the main gun tracking system, the target is an object towed back and forth on a rail at a fixed distance from the tank while the gunner uses the manipulanda in the tank to follow, or pursue the target. The two behaviors are different, but require similar skills.

It was proposed to control the back-and-forth movement of the target according to a pseudo-random schedule which would be the same for each group, but which would differ from trial-to-trial within groups. In this way each group would get the same target movements, but the movements from one target-tracking session to the next would be unpredictable. The gunner would track the target each time it would appear for a certain amount of time. The tracking would end when the commander would give the order to fire.

The movement of the target and the response of the main gun would be recorded by the CDAS for later analysis. This pair of signals would constitute a pair of time functions. The gunner's response error would be defined as the arithmetic difference between the two. The mean absolute value of the difference (MAD) is a descriptor of the subject's accuracy of tracking. Usually the logarithm of the MAD score is used to improve the statistical characteristics of the data (Benignus et al., 1987).

**EEG.** Two channels of EEG were to be collected from the scalp of one of the crewman. Since the gunner was involved in the measurement of one dependent variable, it was decided that the EEG would be measured on the commander. The logic for this decision was that in this way, fewer dependent variables would be collected per subject, thus minimizing the number of crews required to achieve a high-powered statistical test. The method of EEG measurement is discussed in the appropriate instrumentation section. EEG would be recorded by the CDAS and the spectra would be computed off line.

__Speech Discrimination.__ Speech discrimination was to have been measured using a technique similar to the Speech Perception in Noise (SPIN) test (Lewis et al., 1988). Rather than using random noise or other speech as masking, however, it was intended to use the normal background noise in the communication channels of the tank radio and the incidental machine noises in the tank. The speech to be discriminated would be samples of military communications, reconstructed from actual tape recordings made during exercises at Aberdeen Proving Ground (APG), rather than the somewhat artificial sentences in SPIN. The test materials would be recorded and thus the same test would be presented to the commander in each crew. The test score would be the number of correctly identified target words.

The SPIN test is constructed by playing a sentence with good signal to noise characteristics except for the target word at the end of the sentence. The last word is always masked by environmental noise, thus making it difficult to discriminate. For the above experiment, it would be necessary to make new tapes with appropriate military phrases. The task of making such a tape is not trivial. If the subjects could be induced to take the standard SPIN test seriously in the context of a military exercise, it might be preferable to not develop a military version.

The increased specifiability of using a standard test is also advantageous.

STATISTICS

Although the statistical analysis plan must wait until more particulars of the design are available, several general observations may be made. At least one dimension of the experiment, the concentration-effects measurement, will be a repeated measures design. This is because all subjects will be exposed to an ascending-concentration series of CO steps during which their performance will be measured. Different exposure groups may also be composed of the same subjects, depending on the logistics of subject procurement. Repeated-measures analysis has a statistically complicated set of assumptions. Several alternative models are available for the analysis, each with advantages and problems of its own. Selection of an inappropriate model or failure to meet assumptions can lead to either Type I or Type II errors. When the particulars of the experiment are decided, a statistician with experience and current expertise in the area of repeated measures should be consulted before any experimental designs are finalized. Issues of repeated measures are discussed in Hays (1963, Ch. 13).

The use of baseline corrections for the purpose of controlling individual and temporal differences in skill requires the judgment of both the statistician and the scientists in the experiment. The selection of the method of baseline correction will depend upon the design of the experiment, the analysis model selected and the assumptions about the nature of the regression equation for making the corrections. Again, careful, a priori planning is essential.

Given that an experimental design and an analysis plan have been selected, and that a variance (or covariance) estimate is available for the data and that the smallest size of effect to be detected has been decided upon, a power analysis can be performed (Cohen, 1987). The power analysis will assure that enough subjects will be studied to provide a sensitive experiment and statistical test. Since the power of different statistical tests differ according to the particulars of the design, several power analyses should be considered (unless only one design is under consideration). The most sensitive experiment can thus be designed with a minimum of subjects.

An experiment such as that outlined above will be extremely expensive in a number of resources. There is always a strong and legitimate need to obtain as much data from the subjects as possible. This need must be balanced against several negative aspects of making many measures per subject. The main problem is that in most cases, the statistical power of an analysis suffers when many measures are made and the data are legitimately analyzed. If the data are anticonservatively analyzed, there are likely to be more spuriously significant results. This issue is discussed in Muller, Barton & Benignus (1984). Another problem of collection of many variables is that the interaction can become complicated and confusing. Restraint should be exercised in the selection of the number of dependent variables or an expensive study may produce extensive, but flawed data. Again a competent and current statistician should be consulted at the planning stage.

# CHAPTER 2

# EEG HELMET DESIGN, CONSTRUCTION AND TESTING

# CHAPTER 2

# EEG HELMET DESIGN, CONSTRUCTION AND TESTING

## INTRODUCTION

It was planned to collect EEG data during the field experiment. To measure the EEG in a tank posed a number of problems. The major problem was the extensive movement in which the subjects would engage in an actual military exercise. Movement of the electrode wires as the subject moves his head and body could generate large artifactual signals (Craib and Most, 1973). Another problem was the limitation of movement which electrode wires would place upon subjects. A third problem was the high probability that electrodes would become detached from the scalp as the subject worked. It was decided to use head-mounted amplification and radio telemetry to reduce movement problems and to design a helmet to protect the electrodes and telemetry. The system will be called the EEG helmet. A tested, documented prototype EEG helmet was to be delivered.

## METHOD

### ELECTRODES, LEADS AND ATTACHMENT

Silver cup electrodes, 0.5 cm diameter were used for the EEG helmet's telemetry system. The lead to the electrode was a Microdot coaxial cable 34 cm long with the shield grounded at the connector end. A Microtech series B screw-on coaxial connector was used. The shield was terminated 2 cm from the electrode and covered by shrink tubing. For comparison of the performance of the EEG helmet telemetry system to standard EEG methods, Beckman silver/silver chloride cup electrodes 0.5 cm diameter were also used. Standard, unshielded lead wires with pin plugs were attached.

Special consideration of EEG helmet telemetry electrode application is necessary in the case of the proposed field experiment. The work in which the subject will be engaged is such that electrodes which are not well fastened and protected may be dislodged. Furthermore, when the subject moves about, the electrode wires must be prevented from moving because movement would induce artifactual signals into the EEG.

The solution to the above problem was twofold. First the electrodes and their leads were glued to the scalp with collodion. Following this, a modified military helmet was donned by the subject to protect the electrodes and wires from external objects.

Before electrodes were attached, the scalp and forehead sites were vigorously scrubbed, first with an alcohol prep sponge, then with a cotton gauze sponge saturated with Omniprep abrasive (D.O. Weaver & Co., 565-C Nucla Way, Aurora, CO, 80011) and finally with another alcohol prep sponge. The skin area was sufficiently scrubbed to be slightly reddened. The final alcohol scrub removed all of the residual Omniprep solution. As soon as the alcohol evaporated from the scrubbed area, a small quantity of electrode electrolyte (Teca Corporation, Pleasantville, NY) was rubbed in.

Following the scrubs, the electrode cup was filled with Grass EC2 electrode cream. The excess cream was scraped away with a spatula so that the surface of the cream did not extend above the cup. The hair was then carefully parted away from the electrode site (if it was a scalp site) and the electrode was placed onto the site. While the electrode was held in place with a stylus (e.g. a ballpoint pen) placed on the top center, a thin bead of collodion was applied to the circumference of the electrode and surrounding scalp using a plastic squeeze bottle. The electrode lead for about 2.5 cm proximal to the electrode was also glued to the scalp between carefully parted hair. The collodion was dried with a hair dryer until the collodion skinned over and became slightly opaque. Totally, three coats of collodion were applied to the electrode and proximal lead.

When all electrodes were attached, the leads were glued to the scalp, coursing through parted hair in a posterior direction. The wires followed a path parallel to the midline and were glued to the scalp until they reached a point approximately 1 cm below inion and on either side of the skull.

The standard silver/silver chloride electrodes (for comparison to standard EEG methods) were fastened to the scalp after the same scrubbing procedures as above had been followed. The standard electrodes were, however, fastened with the EC2 electrode paste only. The standard electrode wires were simply allowed to course posteriorly without glue and were pinned to the subject's shirt collar to give strain relief. The leads were plugged into a Grass model IGMEB-INT25 electrode box.

EEG helmet telemetry electrodes were located at 03 and 04 and at P3 and P4 in the International 10-20 system (Craib & Most, 1973). The two-channel EEG was measured differentially between these on the left and right side. Two other electrodes were attached above and below the left eye to measure the electo-oculogram (EOG). The standard EEG electrodes were attached to the scalp as close to the bilateral EEG helmet telemetry electrodes as possible and just lateral of them. The distance between differential electrode pairs in the standard EEG system was the same as for the EEG helmet telemetry.

Silver/silver chloride Medi-Trace offset electrodes were applied to sites V5 and right, mid-clavicular ground to measure the electrocardiogram (ECG). Coaxial cables and connectors were used as described above. The cables were not glued down.

**HELMET**

To protect the electrodes from being dislodged or disturbed by the subject as he moves about in the course of task performance, a helmet was worn. A standard helmet (Gentex Corp., Carbondale, PA 18407, Model DH-132) was modified to provide space over the areas where electrodes or wires were located. The space was provided by removing internal helmet padding over those areas so that the electrodes and wires were not in contact with either padding or helmet structures. The helmet was also modified to provide space for housing the telemetry system (see below)

TELEMETRY SYSTEM

The telemetry system was supplied by Bio-Sentry Telemetry Inc. The technical manual of the system is provided with the equipment. Briefly, the system consists of a transmitting module and a receiving module. The transmitting module consists of four channels of high-gain preamplifiers which drive a low-power FM radio transmitter. A battery powers the transmitting system. The FM signal is received and demodulated by an FM receiver. A Grass model 7D polygraph was used to display the demodulated (EEG, EOG and ECG) signals. Low frequency half-amplitude points were 0.15 Hz and the high frequency half-amplitude points were 35 Hz.

The advantage of an FM radio transmitter system is that there are no wires from the subject to instrumentation, allowing free movement. The wires are also a usual source of movement-generated artifactual signals. The possible disadvantage of the radio system of telemetry is that radio frequency interference could be present in areas of use. Such interference would be another source of artifactual signals. Because the radio frequency interference is unique to the environment in which the telemetry is used, no evaluation of the problem was conducted.

The transmission system module was housed in a special fiberglass add-on compartment at the back of the helmet. The transmission module was inserted into a slot and retained in position by a piece of tape. The wires for the electrodes were plugged into the module along the lower, exposed edge. The battery was also contained in the fiberglass housing.

**SUBJECTS**

All subjects were recruited by public advertisement from the population of a small town (mostly students) and were paid for participation. Informed consent was obtained after the subjects read a statement, were given oral explanations and all questions were answered. For the protection of human subjects, the investigators have adhered to the policies of applicable Federal Law (45CFR46). The protocols were approved by the Committee on the Protection of the Rights of Human Subjects of the School of Medicine, University of North Carolina at Chapel Hill and by the Human Use Review Office of the Department of the Army, Office of the Surgeon General.

Before being accepted into the study, potential subjects were given routine physical examinations including a Duke Medical History Form, routine chemical screen (SMA 20) and a Minneapolis Multiphasic Personality Inventory. On the test day the subject also was given a brief medical check-in including measurement of weight, height, age, blood pressure and temperature.

The EEG system was standardized by testing its performance on eight young men under various configurations. After a stable configuration had been selected, three more subjects were tested to evaluate the operating characteristics. Since the data from subjects were only used to demonstrate the system's operation, subject demographics are not given here.

## EXPERIMENTAL DESIGN AND ANALYSIS

The experiment was designed to compare the operating characteristics of the EEG helmet with standard EEG electrodes and amplifiers. The electrodes which were glued on and connected to the radio telemetry system provided a set of signals to the Grass polygraph at high signal levels. The standard electrodes, which were fastened as near as possible to the glued-on electrodes, provided low-level signals to the Grass preamplifiers.

The EEG helmet signals and the standard EEG signals were plotted on adjacent channels to facilitate comparison. The subject was instructed to move in specific ways in order to produce movement-related artifact. The two EEG systems were ranked for amount of artifact. Since standard and EEG helmet signals were collected and displayed simultaneously, the exact quantification of movement was not an issue. The measure of quality of operation was a direct rank comparison of performance in the face of the same movement event. The voluntary movements used to produce artifact were head movements. The subject was asked to nod his head affirmatively at speeds necessary to generate various severity of artifacts. It was desired to provide a range of artifact severities so as to produce interference sufficient to perturb EEG measurement in each system and thereby compare the two.

## RESULTS

The mean electrode impedances for the three experimental subjects for the EEG helmet electrodes was 2.97 k ohms and for the larger standard EEG electrodes was 1.47 k ohms.

Figure 2.1 is a two-channel and ECG collected from subject 3, at rest via the EEG helmet system. Figure 2.2 is a recording of EEG from the P3-03 channel recorded via the EEG helmet system (top channel) and via standard EEG leads (bottom channel). The signals for the two methods, during undisturbed parts of the record, are not identical because the electrodes were in slightly different locations but adjacent to each other. The similarity is sufficient, however to demonstrate that the two systems are operating properly and recording the EEG from similar sites. During head movement, the signal differ markedly.

Figure 2.3 is a set of records to compare the performance of the glued-on shielded wire electrodes with the standard electrodes and wires. In this case both of the pairs of signals were amplified by the Grass preamplifiers.

## DISCUSSION

The EEG helmet transmits clear EEG and ECG signals (see Figure 2.1). The artifact produced by subject head movement is markedly less in the EEG helmet system than in the standard EEG electrodes system (see Figure 2.2). The head movement was produced by vigorous nodding. Other head movements were tried with similar results. It is anticipated that movements related to military activity would also disturb EEG recording considerably less in the EEG helmet system than in other methods of recording. Obviously, sufficient movement velocity can perturb EEG recording even for the helmet system. The limiting variables are the movement of the scalp or movement of electrodes relative to the scalp. It is possible that use of larger electrodes in the EEG helmet system would yield even less artifact due to lowered impedance.

Apparently, the superior performance of the EEG helmet system is due to the elimination of wire movement for low-level EEG signals. Figure 2.3 demonstrates that even when low-noise wires are glued to the head, movement artifact will occur if the wires are allowed to move after they leave the head. The EEG helmet prevents this by amplifying the signal first and then transmitting it by radio rather than over wires.

The model of EEG helmet supplied as part of the present project is considered a prototype. Construction of other units is considered to be a simple matter since there is little problem with reproducing the mechanical parts of the prototype and since the electronics was purchased from a supplier which can produce other units of its kind. No special equipment was used in the construction. At such time as it might be desirable to construct another unit, it would be wise to do product research on electronics which might have been developed in the interim and might offer improved performance.

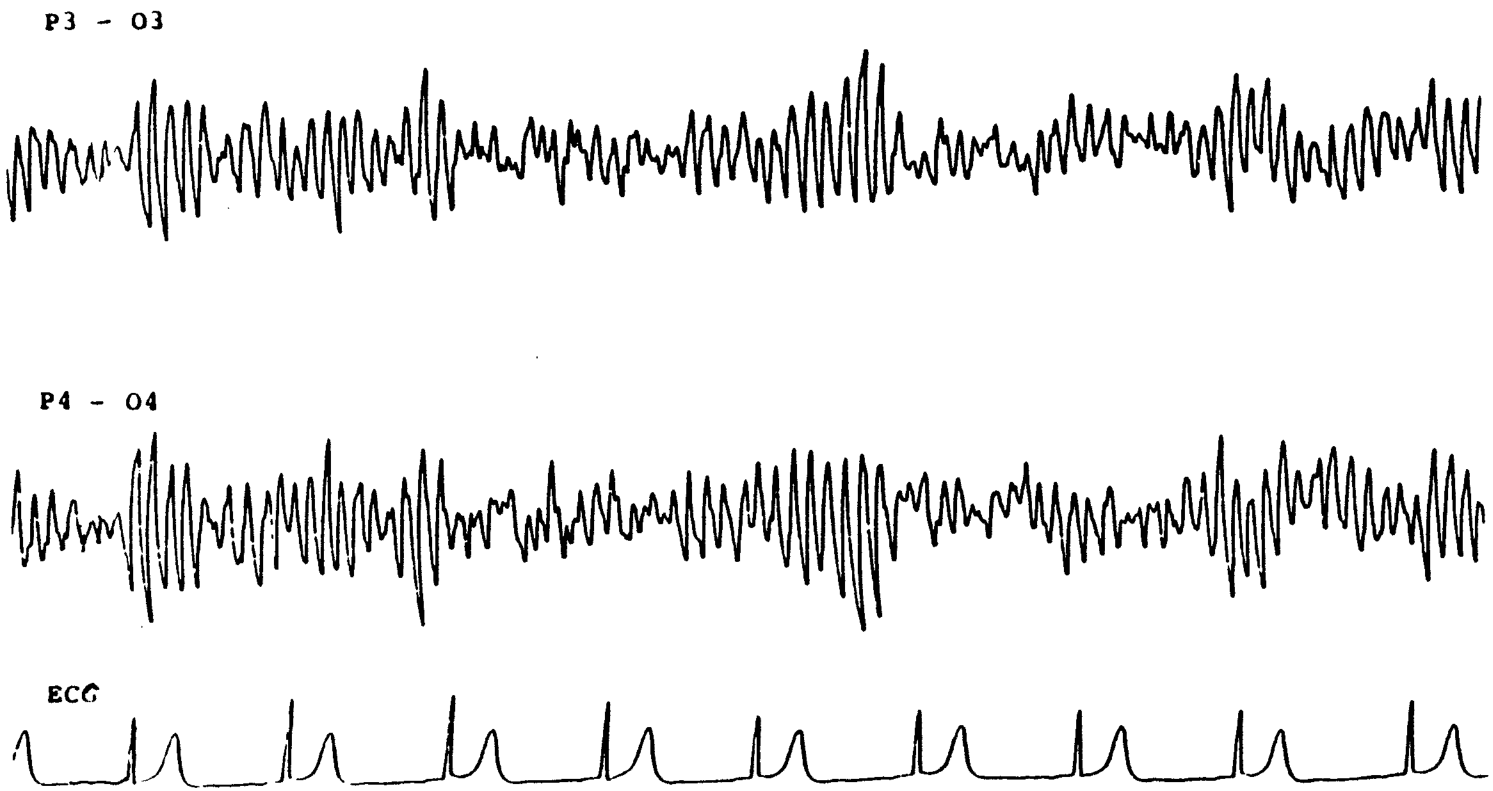



Figure 2.1. Two EEG channels and the ECG as transmitted by the EEG helmet system (subject 2).

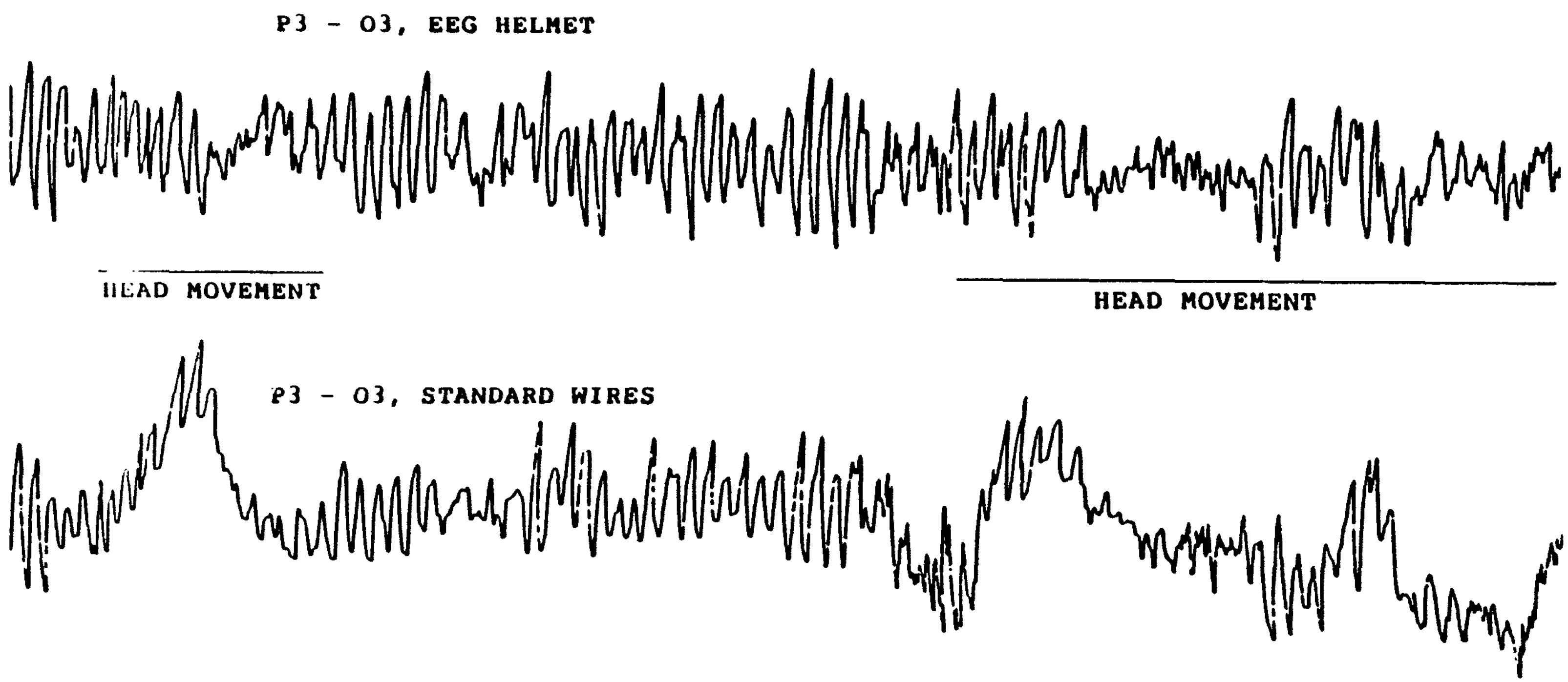



Figure 2.2. EEG recorded from EEG helmet telemetry system (top channel) and from standard wires (bottom channel). Horizontal lines show duration of head movement.

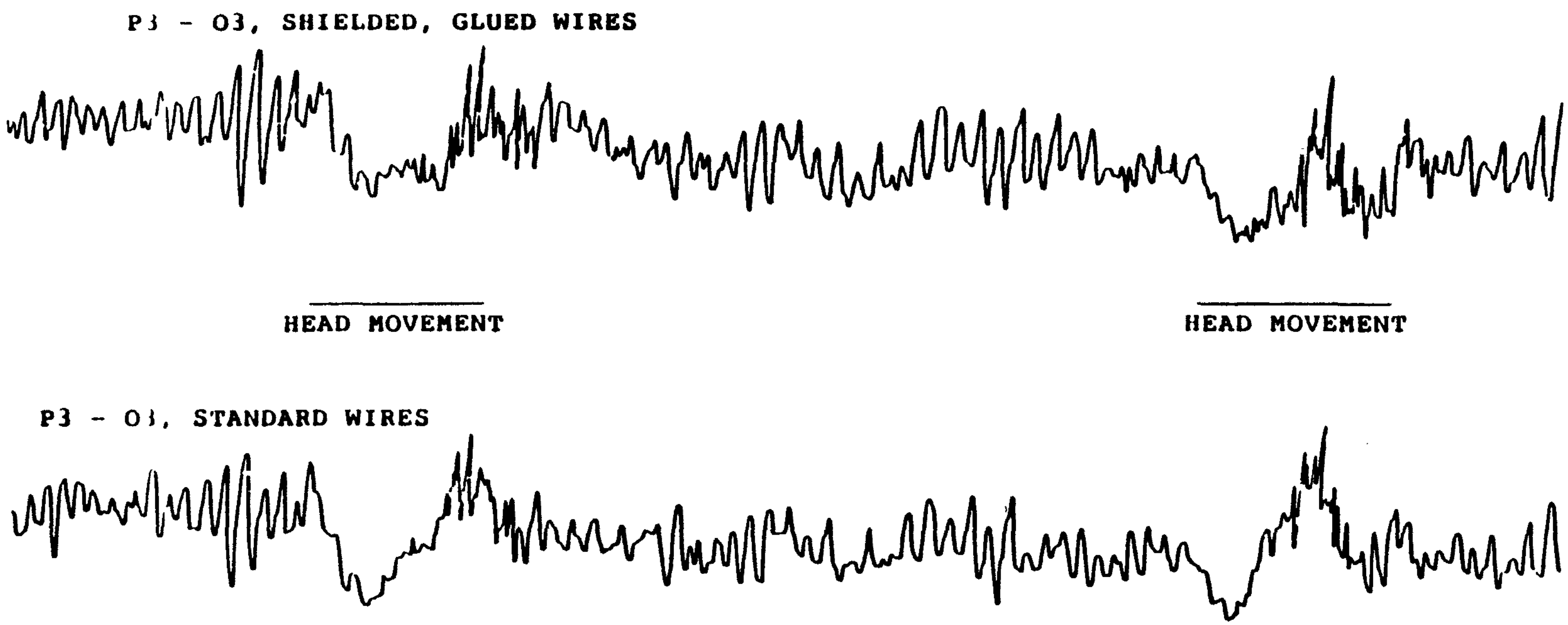



Figure 2.3. EEG recorded from shielded, glued wires (top channel) and from standard wires (bottom channel). Horizontal lines show duration of head movement.

# CHAPTER 3

# FACEMASK EVALUATION EXPERIMENT

# CHAPTER 3

# FACEMASK EVALUATION EXPERIMENT

## INTRODUCTION

Another problem in the field experiment was to deliver known amounts of CO (and other pollutants) to the subject. To this end, a project was initiated to evaluate a number of commercial facemasks and select (but not supply) one which had the following characteristics:

(1) low gas leakage around the edges

(2) have minimum effect on respiration

(3) allow free head movement and interfere minimally with vision and speech

(4) be comfortable for the duration of the study

(5) require minimum difficulty with fitting to subjects.

**LEAKS**

The amount of leakage varies with the construction and material of the seals. Seals may be made either of plain latex or of gas-filled latex (pneumatic seals). The operation of the seals is also influenced by the rigidity of the mask shell. Pneumatic seals appeared to provide better seals (Griffin and Longson, 1969; 1970) although they tended to be more fragile and required more skill to fit to a wide variety of faces, especially those masks with with rigid shells (Binning, 1965). Heavy facial sweating helped maintain a seal (Dahlback and Novak, 1983) while facial hair impaired the seal (Hyatt et al., 1973; Skretvedt and

Loschiavo, 1984).

**BREATHING**

The effects of a face mask on breathing pattern have been studied. Mask breathing did not significantly affect the frequency of respiration, but did increase the tidal volume (Hirsch and Bishop, 1982; Segal, 1987). Tidal volume increased more than was expected due to the increased deadspace of the mask. Increased resistive loading of a mask in the above studies tended to decrease tidal volume, however. Increased resistance during submaximal exercise decreased peak inspiratory flow rates and, subsequently, both the inspiratory and expiratory time (Harber et al., 1982).

Besides changes in respiratory variables, a slight increase in $P_aCO_2$ and minute ventilation has been observed during both rest and moderate exercise as compared to unimpeded breathing (White et al., 1975). The latter effect was slight but might contribute to general fatigue. Indeed, reduced maximal work capacity, shortened time to exhaustion, increased cardiac work and decrements in work efficiency during submaximal and maximal work performance have been reported in persons wearing various respirators (Raven et al., 1979).

The key determinants of mask performance are inspiratory and expiratory resistance (Bentley et al., 1973) and deadspace (Thomas, 1967). The higher the resistance and the larger the deadspace, the poorer the mask performance. Mathematical models incorporating these key variables have been developed to characterize the range of acceptable performance of masks (Johnson and McCuen, 1980).

**MISCELLANEOUS**

Mask wearing also increased the number of operator errors and time needed to perform simple tasks (Spioch et al., 1962). Discomfort of the mask might also interfere with performance of delicate tasks (Raven et al., 1979; Snook et al., 1966). If the mask's attached apparatus is too cumbersome, the effects of discomfort could be increased.

## METHOD

**SELECTION OF CANDIDATE MASKS**

The principal investigator (second author) selected from the commercially available sources of half-face masks, the most likely candidates for testing. The selection was based upon the specification supplied by the manufacturer as compared to the characteristics of the masks which have done well in other tests. The requirements for other characteristics listed in the introduction also entered into the decision. In this phase of the study, it was anticipated that all but a few masks would be eliminated due to obvious problems.

**SUBJECTS**

Subjects were 20 healthy, non-smoking, clean-shaven men aged 18-35 yrs. All subjects were recruited by public advertisement from the population of a small town (mostly students) and were paid for participation. Informed consent was obtained after the subjects read a statement, were given oral explanations and all questions were answered. For the protection of human subjects, the investigators have adhered to the policies of applicable Federal Law (45CFR46). The protocols were approved by the Committee on the Protection of the Rights of Human Subjects of the School of Medicine, University of North Carolina at Chapel Hill and by the Human Use Review Office of the Department of the Army, Office of the Surgeon General.

Before being accepted into the study, potential subjects were given routine physical examinations including a Duke Medical History Form, routine chemical screen (SMA 20) and a Minneapolis Multiphasic Personality Inventory. On the test day the subject also was given a brief medical check-in including measurement of weight, height, age, blood pressure and temperature.

**MEASUREMENT OF LEAKAGE**

For testing any given mask, each subject was custom fitted with the mask using both visual inspection and feedback from the subject. The subject was then seated inside a body plethysmograph (body box) and was allowed to adapt to the mask while the mask was connected to the fittings. The mask inhalation port was connected to the air supply line which, via one of the body box ports, was open to room air. The exhalation port of the mask was connected, via another of the body box ports, to a three-way valve so that exhalate could be either into room air or into a 30 liter latex meteorological balloon for sample collection.

After the subject had been enclosed in the body box, sufficient helium was introduced into the box to bring the atmospheric level of helium to ca. 13% as continuously measured by a Perkin-Elmer model MGA-1100 mass spectrometer. The helium level was recorded at the beginning, middle and end of the measurement period to assure that no appreciable change occurred. The helium level in the room air (which the subject inhaled) was also measured by the mass spectrometer.

After the helium level in the box had been stabilized, the subject's exhalate was switched into the meteorological balloon for collection. The subject sat quietly breathing room air for most of a 10-min test period. During the middle of the test period, the subject was required to move his head up and down and side to side and to read a short (83 words, 126 syllables) standard paragraph aloud. Head movements consisted of slowly nodding once followed by one side to side movement.

At the end of the 10-min exposure period, the concentration of helium in the latex bag was measured with the mass spectrometer. The bag helium concentration was corrected by subtracting the room-air helium level. The mean helium concentration in the body box was computed for the three measures (beginning, middle and end). The percent leakage of the mask was computed as

$$PCT\ LEAK = \frac{(CORRECTED\ BAG\ CONCENTRATION)}{(BODY\ BOX\ CONCENTRATION)} \times 100.$$

Each mask was tested three times and the PCT LEAK was averaged over the three trials to produce a mean percent leak score. The latter was used in the analysis of mask data.

### SUBJECTIVE EVALUATIONS

At the end of the three 10-min mask trials, the subject was asked to rate the mask on various scales. The ratings of the subject on each scale were used to compute the median score on each of the scales for each of the masks.

### PROCEDURE

Each subject was used to evaluate two of the candidate masks. For any given subject, the order in which masks were tested was random. After the two candidate masks were tested, the subject was discharged.

### DATA ANALYSIS

Because each subject was tested with two masks, the leakage difference for each pair of masks was to be evaluated with subject physiognomy held constant. This was to be done with Student's t tests of the difference of the leakage scores for each pair of masks. Median mask ratings were to be used for descriptive purposes only.

## RESULTS

### MASKS SELECTED

Three facemasks were selected for testing as representative of classes of available masks. Appendix 3.1 includes the manufacturers' specifications for each mask. **Mask 1** was a single-use, clear mask (Vital Signs, Inc. adult model). **Mask 2** was a pulmonary function laboratory mask (Hans Rudolph series 9700). **Mask 3** was a military aviator's mask (Gentex model HA/LP-PPB).

LEAKAGE DATA

__Screening of Data.__ Standard screening statistics revealed that the distributions of percent leakage were strikingly non-Gaussian (see Figure 3.1). Most leaks were less than 2.5% for each mask, but each mask leaked substantially more than that on at least two occasions. Such distributions precluded the planned simple use of t tests. It was decided to treat the leaks as two classes of events; small and large leaks. The small leaks (<2.5%) were considered to be representative of properly-functioning masks. The larger leaks (>2.5%) were considered to be representative of mask failures. The consequences of the analysis plan changes are (a) the a priori nature of the significance tests was altered (b) the number of observations were reduced, making the tests less powerful and (c) more tests had to be conducted, thus increasing the probability of an experimentwise Type I error.

__A Priori Tests.__ Table 3.1 gives the leakage comparisons for the three pairs of masks with the originally planned t tests, but with the large leaks dropped from the data. Only four pairs of observations remained. No pair of masks differed significantly.

__Exploratory Analyses.__ Further exploratory tests were performed on the leakage data. For the exploratory tests, the pairwise nature of the data was ignored and all observations were simply pooled, i.e, the data were treated as if all observations were independent. This was done to increase the test power by obtaining more observations per test at the expense of increasing the probability of experimentwise type I error.

Table 3.2 gives the results of a comparison of the unedited leakage data, Table 3.3 gives a comparison of the large leaks and Table 3.4 gives a comparison of the small leaks. No significant differences were found in any of the exploratory comparisons.

Mask Ratings. Table 3.5 gives the median rating values for the three masks on eight scales. The scales were constructed so that zero indicated no problem, while 4 indicated severe problems. Thus smaller numbers indicate better ratings.

## DISCUSSION

No differences in leakage was found among the three masks. The a priori tests were, however, of extremely low power due to the editing of the large leak observations. When exploratory analysis was performed on the pooled low-leak data (ignoring the pairwise nature of the observations) there were still no significant differences despite the over-sensitive nature of the test. The p value was close to significant ($p < 0.09$) and it is possible that a larger number of subjects would have resulted in statistically significant differences. The means would imply that in a larger experiment, mask 3 would be best and mask 2 worst. The differences in the small leaks was very small, however, and the leaks were of small consequences for all but the most exacting applications.

The three masks were tested for differences in the size of large leaks (see Table 3.3) but there were only 2 and 6 degrees of freedom and variance was large. The test was, therefore, not very powerful. To evaluate the difference between the three masks with respect to large leaks (mask failures) would require a considerably larger group of subjects because of the low probability of such failure.

When the rating data are considered, mask 2 was best in five out of eight cases. In two of the remaining scales, the differences between mask 2 and mask 1 were trivial. Mask 1 was best in overall comfort.

Perhaps the most important finding of the present study was that all of the masks failed (leaked substantially more than 2.5%) under some conditions. Such large leaks with such high probabilities is a serious matter for reasons of safety if the masks were to be used for protection and would seriously affect experimental measurement of gas concentrations in inhaled air as well as pulmonary function. It is probable that facemasks, in general, are unsuitable for experimental or protective purposes. For experimental needs, it is probably better to deliver gases via a bite-type mouthpiece with nose clamp, despite the discomfort, speech restriction and non-representative nature of the method. For protective purposes in toxic-gas environments, protective suits which fully enclose the body would seem to be better.

TABLE 3.1

LEAKAGE COMPARISONS FOR PAIRS OF FACEMASKS,

LEAKS ABOVE 2.5% ELIMINATED

| MASK PAIR | MEAN | SD | MAX | MIN | N | t | p< |
|---|---|---|---|---|---|---|---|
| 1 | 0.70 | 0.77 | 1.51 | 0.00 | 4 | 1.71 | 0.19 |
| 2 | 1.06 | 0.46 | 1.29 | 0.37 | | | |
| 1 | 0.48 | 0.29 | 0.74 | 0.21 | 4 | -0.02 | 0.98 |
| 3 | 0.48 | 0.17 | 0.67 | 0.27 | | | |
| 2 | 1.03 | 1.04 | 2.29 | 0.15 | 4 | 1.43 | 0.25 |
| 3 | 0.29 | 0.06 | 0.35 | 0.21 | | | |

TABLE 3.2

LEAKAGE STATISTICS FOR FACEMASKS,

POOLED DATA, ALL OBSERVATIONS INCLUDED

| MASK NO. | MEAN | SD | MIN | MAX | N | F | df | p< |
|---|---|---|---|---|---|---|---|---|
| 1 | 2.54 | 6.16 | 0.00 | 22.55 | 13 | 0.74 | 2,36 | 0.93 |
| 2 | 3.45 | 4.04 | 0.37 | 12.36 | 14 | | | |
| 3 | 3.25 | 8.60 | 0.21 | 30.26 | 12 | | | |

TABLE 3.3

LEAKAGE STATISTICS FOR FACEMASKS,

POOLED DATA, LARGE LEAKS ONLY

| MASK NO. | MEAN | SD | N | F | df | p< |
|---|---|---|---|---|---|---|
| 1 | 13.77 | 12.41 | 2 | 0.83 | 2,6 | 0.48 |
| 2 | 8.00 | 3.42 | 5 | | | |
| 3 | 17.58 | 17.93 | 2 | | | |

TABLE 3.4

LEAKAGE STATISTICS FOR FACEMASKS,

POOLED DATA, SMALL LEAKS ONLY

| MASK NO. | MEAN | SD | N | F | df | p< |
|---|---|---|---|---|---|---|
| 1 | 0.50 | 0.50 | 11 | 2.69 | 2,27 | 0.09 |
| 2 | 0.93 | 0.78 | 9 | | | |
| 3 | 0.39 | 0.18 | 10 | | | |

TABLE 3.5

MEDIAN RATINGS OF FACEMASKS[1]

| FACTOR | MASK 1 | MASK 2 | MASK 3 |
|---|---|---|---|
| OVERALL DISCOMFORT | 1.64 | 1.85 | 2.17 |
| VIEW OBSTRUCTION | 2.25 | 0.64 | 1.58 |
| MOTION RESTRICTION | 1.50 | 1.67 | 1.83 |
| SPEECH INTERFERENCE | 1.75 | 1.56 | 1.87 |
| FACE PRESSURE | 2.75 | 1.00 | 1.50 |
| FITTING DIFFICULTY | 2.31 | 1.60 | 2.21 |
| INSPIRATORY RESISTANCE | 0.81 | 0.64 | 0.92 |
| EXPIRATORY RESISTANCE | 0.69 | 0.70 | 1.25 |

[1]Ratings were on a 0-4 scale, zero indicates no problems, four indicates severe problems.

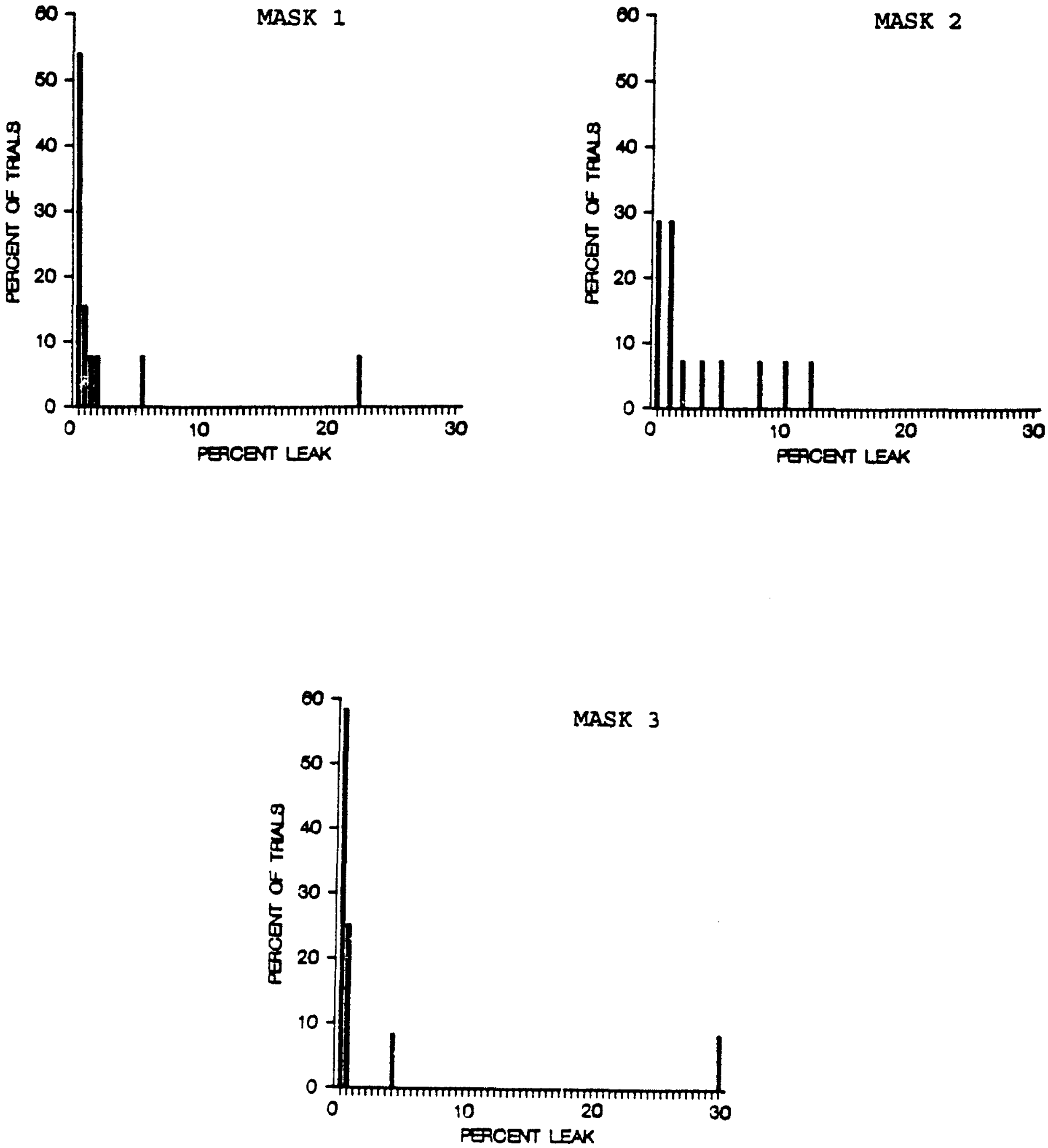



Figure 3.1. Distributions of leakage measures for each of the masks.

# APPENDIX 3.1

## MANUFACTURER'S DATA ON MASKS 1, 2 AND 3

MASK 1, MANUFACTURER'S DATA

# ...Now with Six Sizes

The original single-use, low pressure face mask from Vital Signs is the #1 face mask in the U.S.[1] Used in over 12 million procedures.

## Six Reasons to Choose Vital Signs:

### Patent Pending Inflation Valve

- The only mask that allows you to adjust the cushion by syringe or mouth
- Allows you to customize the cushion and seal to your patient's needs

### Low Pressure Seal

- Soft, pliable, air filled cushion molds gently to all parts of face with a low pressure seal
- Superior seal reduces waste anesthetic gas pollution[2]

### Clarity

- Allows early recognition of regurgitation or silent aspiration[3]
- Ideal for OB anesthesia, resuscitation, as well as general anesthesia

### Single Patient Use

- Low cost makes single patient use a reality
- Reduces cross-infection[4]
- Eliminates burns or irritation caused by retention of disinfectants or sterilization agents

### Traditional Anatomical Shape

- Easy to grip for induction or resuscitation

### Removable Hook Ring

- Accommodates traditional anesthesia head straps

**Ordering Information**

| | | |
|---|---|---|
| 5210<br>5211 | Neonate | 20/cs<br>100/cs |
| 5220<br>5221 | Infant | 20/cs<br>100/cs |
| 5230<br>5231 | Toddler | 20/cs<br>100/cs |
| 5240<br>5241 | Child | 20/cs<br>100/cs |
| 5245<br>5246 | Adult Classic | 20/cs<br>100/cs |
| 5250<br>5251 | Adult | 20/cs<br>100/cs |
| 9102 | Flat Head Strap | 1 ea |

Also available with Vital Signs breathing circuits.

[1] 1st QTR 1988 HOSPITAL SUPPLY INDEX DATA.

[2] Whitcher C; Occupational Exposure, Education and Sampling Methods. ANESTHESIOLOGY. 51 (Suppl) S336, 1979

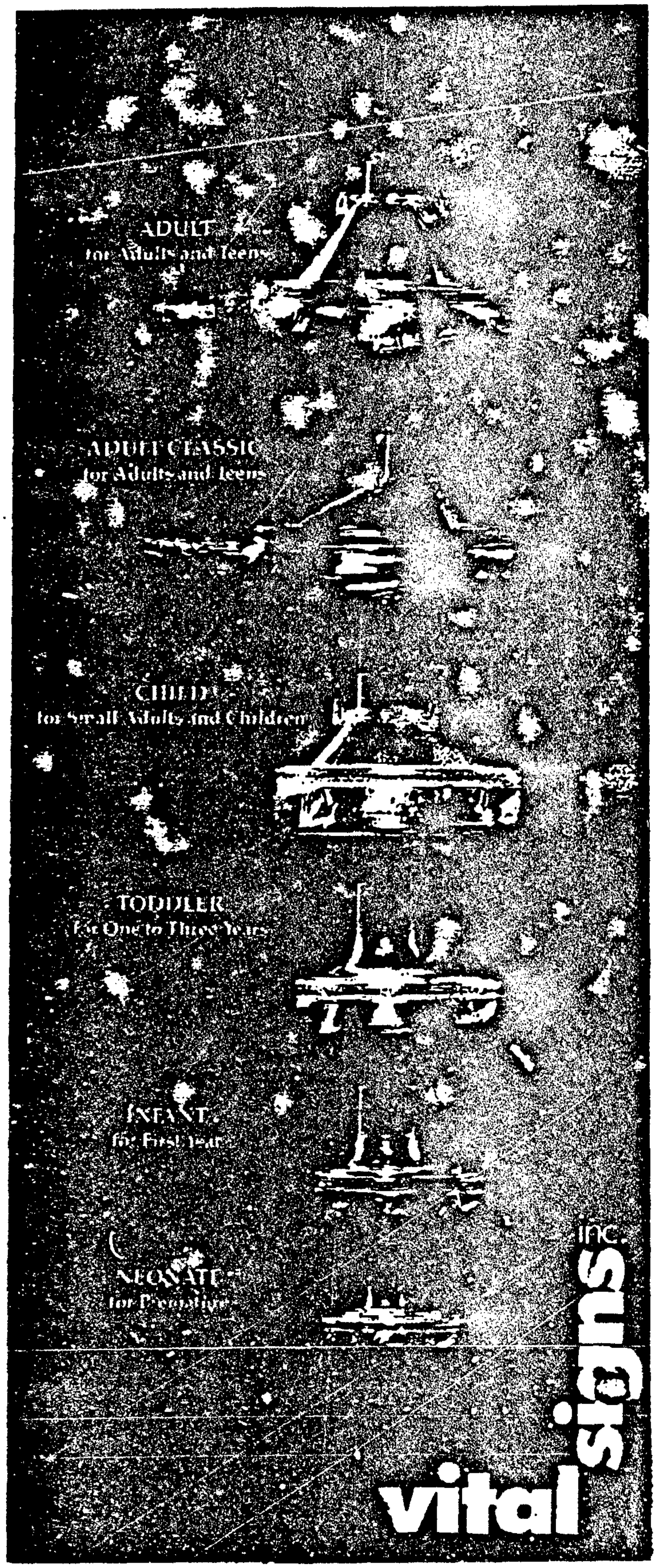
[3] Stetson JB: Patient Safety: Prevention and Prompt Recognition of Regurgitation and Aspiration. ANESTHESIA AND ANALGESIA 53:142-147, 1974

[4] Pandit SK, Mehta S, Agarwal, SC: Risk of Cross Infection from Inhalation Anesthetic Equipment. BRIT J ANESTH 39:838-844, 1967

Caution: Federal law restricts this device to sale by or on order of a physician.

Warning: Do not use in the presence of flammable anesthetics. Single use only.





## MASK 1, MANUFACTURER'S DATA

... Product Info..

**HANS RUDOLPH, INC.**

RUDOLPH FACE MASK
Series 7900

Our New Breathing Mask with inhalation / exhalation valve diaphragms is designed for exercise testing. It is especially useful with patients who have difficulty in using the more common mouthpiece, noseclip and our 2-Way Non-rebreathing valve set up.

This revolutionary **Rudolph Mask** provides an excellent solution to overcome the previous problems of face masks, i.e., facial sealing, slipping during exercise, achieving a minimum dead space, minimal inhalation / exhalation resistance to flow and capability of gas sampling.

The patient comfort afforded with this mask, which usually results in more accurate test results, is very important factor. For example, as compared to a mouthpiece setup, this mask eliminates saliva build up, dry mouth, and throat irritation. It allows communication between patient and technician.

For additional information on the effects of breathing patterns comparing the face mask with mouthpiece technique, refer to "Human breathing patterns on mouthpiece of face mask during air, $CO_2$ or Low $O_2$" by Judith Ann Hirsch and Beverly Bishop, Journal of Applied Physiology, Nov 1982-Vol. 53 No. 5, pages 1281-1290. The mask discussed in the article is not this **Rudolph Mask.**

**Mask Face Piece**** - Molded of tufel* silicone rubber which is durable, resilient, hypoallergenic (safe for all skin types), comfortable to facial skin, resistant to oxidation and chemical degradation.

- Double lip facial seal - conforms without creating pressure points.
- Chin nest prevents slipping, especially when perspiring during exercise testing.
- Elastic headband straps, easily adjusted for a comfortable four-point suspension fit with minimal tension to hold mask firmly in place.
- Tufel* outlasts theromplastic and organic rubber more than ten to one.

**Three Sizes Available** - For optimum fit and appropriate breathing parameters such as dead space and flow requirements.

- Cat #7900-L Large for Large Adult.
- Cat #7900-M Medium for Average Adult.
- Cat #7900-S Small for Small Adult and Pediatric.
- Refer to legends for typical mask dead space and resistance to flow.

**Valving** - Utilizes two inhalation ports and one exhalation port.

- Uses our patented, time proven low resistant molded silicone Spiral Diaphragms.
- Diaphragm sizes used in the inhalation / exhalation ports are shown in legend.
- All port tube adapters are for standard large 1 3/8" Bore Tubing.

**Gas Sampling Ports**

- One in mask body for breath by breath analysis.
- Hose barb is for 3/32" I.D. Tubing.



Ref 691094-1 4/86 7200 WYANDOTTE KANSAS CITY, MO. 64114 816 363-5522

# MASK 2, MANUFACTURER'S DATA

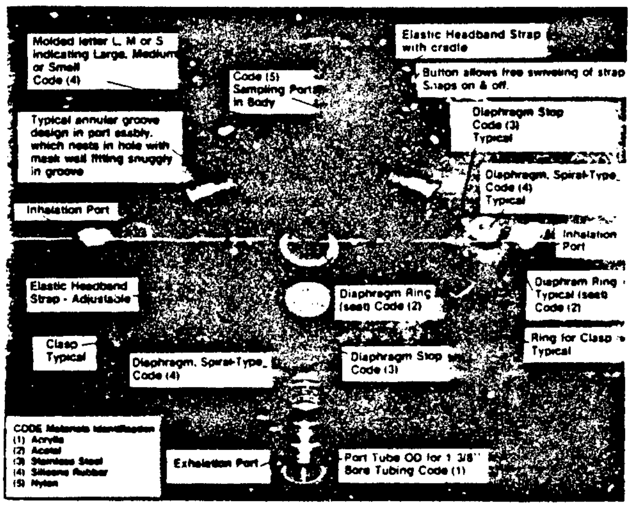
## LEGEND OF PERTINENT DATA

| | *ITEM | LARGE ADULT | AVERAGE ADULT | SMALL ADULT & PEDIATRIC | REQUIRED PER MASK |
|---|---|---|---|---|---|
| MODEL (order by #) | N/A | #7900-L | #7900-M | #7900-S | N/A |
| Letter on Mask noting size | N/A | "L" - Large | "M" - Medium | "S" - Small | N/A |
| Typical Patient Fit | N/A | Large Adult | Average Adult | Small Adult & Ped. | N/A |
| · Typical Dead Space | N/A | 195 cc | 185 cc | 145 cc | N/A |
| (Approximate dead space in mask when measured on average subject.) | | | | | |
| Weight | N/A | 9 OZ | 9 OZ | 6 OZ | N/A |

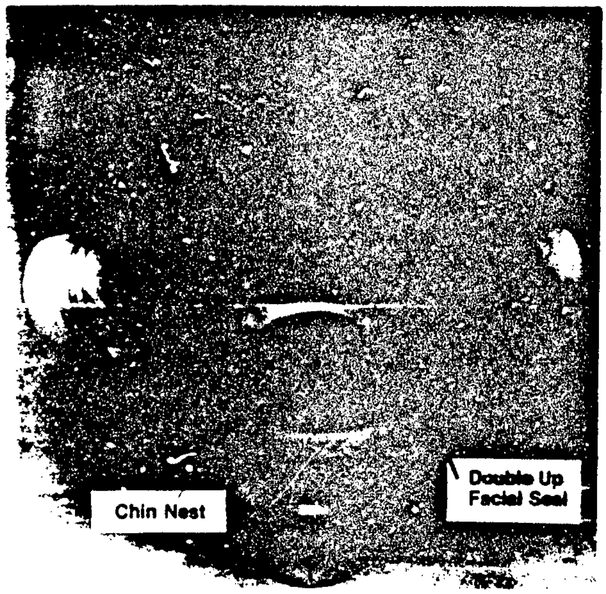
**Replacement Parts (Order by #):**

| | *ITEM | LARGE ADULT | AVERAGE ADULT | SMALL ADULT & PEDIATRIC | REQUIRED PER MASK |
|---|---|---|---|---|---|
| Headband. Elastic Strap - **Includes cradle:** | | | | | |
| One Set | N/A | #7901 | #7901 | #7901 | One Set |
| Cap for Sampling Port | N/A | #1911 | #1911 | #1911 | ONE |
| Exhalation Port (One): | | | | | |
| Diaphragm | A | #2708 | #2708 | #2608 | ONE |
| Diaphragm Stop | D | #5703 | #5703 | #5603 | ONE |
| Inhalation Ports (Two): | | | | | |
| Diaphragm | B | #2606 | #2608 | #2608 | TWO |
| Diaphragm Stop | C | #5603 | #5603 | #5603 | TWO |

*ITEM - Refer to expanded illustration for identification




EXPANDED ILLUSTRATION




INSIDE VIEW OF SILICONE RUBBER FACE PIECE

| Resistance to Flow - mm $H_2O$ Pressure | | | | |
|---|---|---|---|---|
| LPM | #7900 L & M INH. | #7900 L & M EXH. | #7900 S INH. | #7900 S EXH. |
| 100 | 4 | 7 | 5 | 8 |
| 200 | 9 | 12 | 13 | 26 |
| 300 | 17 | 19 | 23 | 53 |
| 400 | 29 | 28 | 40 | 87 |
| 500 | 44 | 37 | 58 | 130 |
| 600 | 62 | 48 | 80 | 180 |
| 800 | 106 | 68 | 132 | 270 |

**Maintenance, Cleaning, Inspection -**

- The port assemblies are easily dissassembled and reassembled:
  **To remove valve port assemblies:** Grip mask firmly with fingers on inside and thumb on exterior next to port. Hold port with other hand and apply a force 90° to side of mask. The mask wall, which is sandwiched in the ports groove, will slip free from groove.
  **To replace:** Grip firmly as in disassembly and manipulate groove of port into its respective hole in mask wall. Once port assembly is in mask, rotating it is difficult. This procedure is typical for all three ports on each size mask.
  Each individual port assembly can be disassembled by unscrewing mating parts, for cleaning and parts replacement.
- Do Not Autoclave. We recommend ETO or cold sterilization. Follow manufacturers instructions. Avoid alcohol on the transparent acrylic parts.
- Inspect the mask before usage for cleanliness, diaphragm in proper position for flow direction and sampling ports capped if not used.
- Beards are limiting factors and will possibly result in leakage.

* Tufel is a registered trademark of General Electric, Slicone Division.

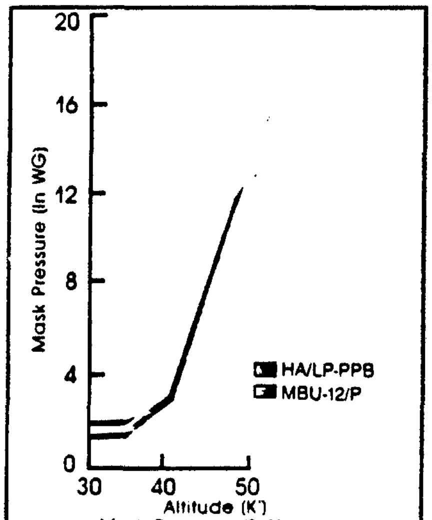
** Silicone Rubber Mask Face Piece is the product of Survivair. A division of U.S.D. Corp. A subsidiary of Liquid Air Corp. of North America. Some statements reflect information from their product literature "Blue 1 TM Air Purifying Respirators."

# Technical Information

**Mask Configurations**
HA/LP is one-to-one replacement for the MBU-5/P, MBU-12/P, MBU-14/P thru MBU-17/P Series masks.

**Breathing Valves**
Exhalation: Pressure compensated valve designed to meet MIL-V-25126
Inhalation: Designed to meet leakage and flow rate requirements of MIL-V-21701A.

| Measured Leak Rates | |
|---|---|
| **Mask Pressure** (Inches $H_2O$) | **Outboard Leak** (LPM) |
| 15.9 | 0 |
| 21.2 | 2 |
| 25.6 | 4 |




Mask Pressure VS Altitude
FLow=25 LPM

**Communications Objectives**
Standard: Dynamic microphones as used in the MBU-12/P and MBU-14/P thru MBU-17/P Series masks.

**Helmet Compatibility**
Compatible with HGU-26/P, HGU-33/P, HGU-34/P, HGU-55/P, HGU-55/G, and SPH Series helmets.

**Changes Required**
Use of HA/LP requires no changes to aircraft, crew-member's helmet, or helmet communications equipment; a new visor trimmed to match HA/LP-PPB contours is required.

**Features**
- Separate inhalation and compensated exhalation valves for ease of breathing.
- Comfortable, low profile silicone rubber faceseal.
- Separate hardshell and faceseal.
- Side entry hose to bring mask CG close to face.
- Small mask faceseal area which seals on the supramentale (between lower lip and chin) rather than under chin.
- Small volume dead air space.
- Improved downward vision.

| Replacements for Standard Military Masks | | |
|---|---|---|
| **MBU-5/P Mask** Size | **HA/LP** Size | **HA/LP** Part Number |
| Short Narrow | Small | G010-1030-01 |
| Reg Narrow | Medium | G010-1030-02 |
| Reg Wide | Large | G010-1030-03 |
| Long Narrow | X-Large | G010-1030-04 |
| **MBU-12/P Mask** Size | **HA/LP** Size | **HA/LP** Part Number |
| Short | Small | G010-1030-01 |
| Regular | Medium | G010-1030-02 |
| Long | Large | G010-1030-03 |
| X-Long | X-Large | G010-1030-04 |
| **MBU-14/P Mask** Size | **HA/LP** Size | **HA/LP** Part Number |
| Short | Small | G010-1034-01 |
| Regular | Medium | G010-1034-02 |
| Long | Large | G010-1034-03 |
| X-Long | X-Large | G010-1034-04 |

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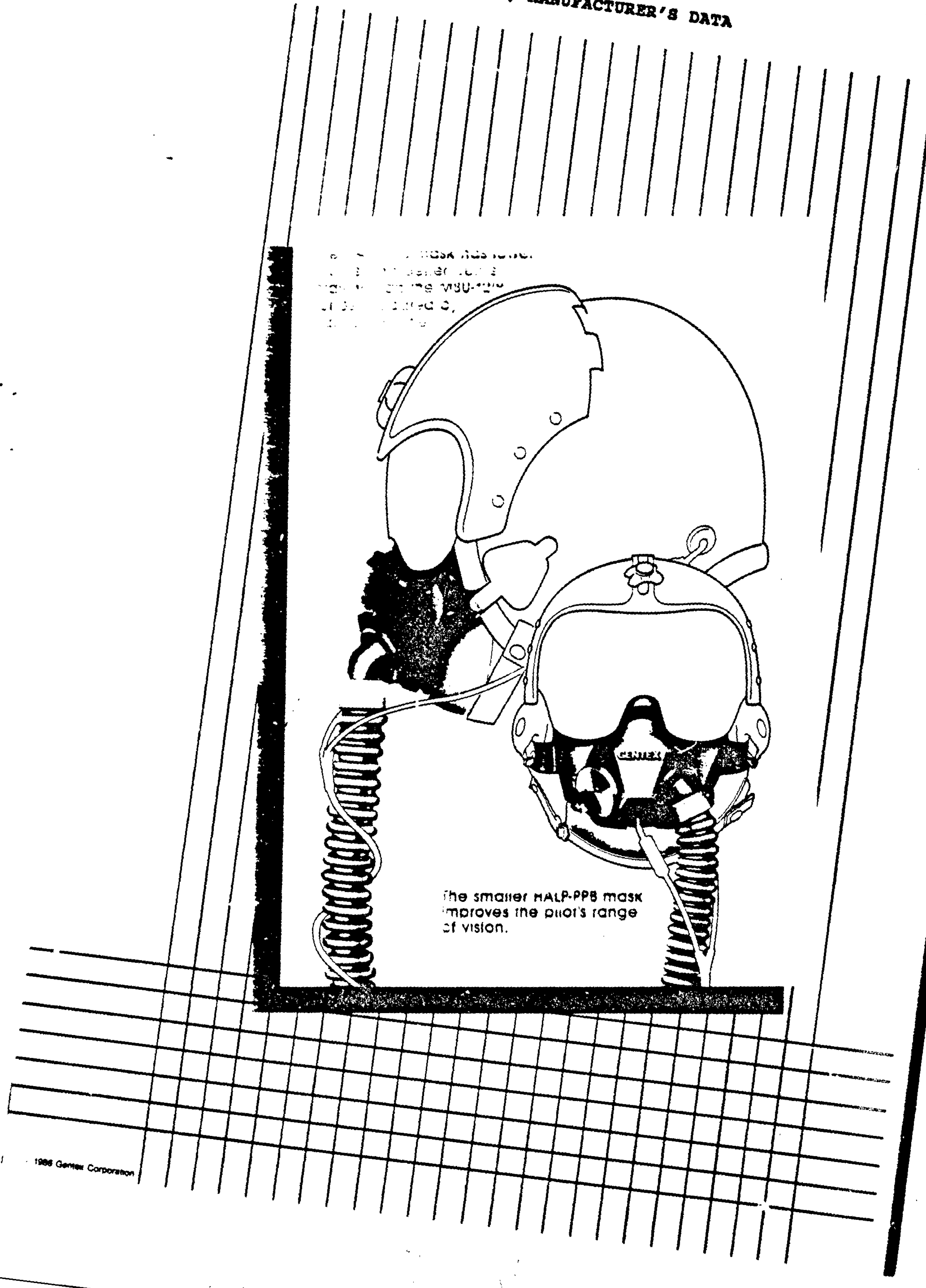
GENTEX
The smaller HALP-PPB mask improves the pilot's range of vision.
1986 Gentex Corporation

# CHAPTER 4

## CONTROL AND DATA ACQUISITION SYSTEM

## (CDAS) DESIGN, CONSTRUCTION AND SPECIFICATIONS

# CHAPTER 4

# CONTROL AND DATA ACQUISITION SYSTEM (CDAS) DESIGN, CONSTRUCTION AND SPECIFICATIONS

## INTRODUCTION

A central computer was to be used to (1) control the manipulation of the independent variables (2) control presentation of stimuli (3) collect data from the various devices measuring environmental events (4) collect data from the devices measuring behavior and EEG and (5) store the data in a documented file in which all data maintained temporal relationships to each other. The CDAS was to be flexible in function and therefore usable for more than one experimental design. Both hardware and software were to be designed to make the CDAS a general purpose device. The CDAS was to be supplied to the Army for the field experiment. The CDAS has been designed and constructed. The following is a description and specification.

## HARDWARE

Figure 4.1 is a block diagram of the CDAS system hardware. In the following description, the reader may find it helpful to refer to the block diagram. When reference is made to any of the blocks in Figure 4.1, the name of the block will be capitalized.

### CDAS WIRING PATCH PANEL

The CDAS WIRING PATCH PANEL is the central piece of hardware in the CDAS, a MAC/PANEL model 719423 No 115. All wiring between the various instruments and equipment is accomplished on this panel. The device consists of a 30-row by 40-column set of female sockets. A matching board containing plug-in male connectors and wires is used to make wiring interconnections. The board is placed into the female panel and pushed into place by a lever. The entire CDAS will not function unless its subcomponents are wired together on this panel. Thus the CDAS consists of an unconnected set of devices for control and data collection instruments, the electrical function of which is defined by the wiring of the CDAS WIRING PATCH PANEL. The operation of the CDAS is controlled by software (see below). The permanent connections to the patch panel are given in an alphabetical and a numerical log or index book (provided with the equipment). In the alphabetical book, equipment is listed in alphabetical order along with the points to which input and output are connected. In the numeric book, the points are listed in numerical order and the function of each point is given. By consulting these books a user can make appropriate connections. Wiring schedules for the location and function of all connections for the patch panel are provided with the equipment.

**MICROPROCESSOR**

The microprocessor selected was an IBM PC/XT with 640K of memory, two 10M hard disk drives and one 360K floppy disk drive. An expansion unit was provided to house interface hardware. Complete specifications and manuals are provided with the equipment.

**DIGITAL AND ANALOG I/O**

The interface hardware which is directly connected (hard-wired) to the microprocessor consists of multiple channels of DIGITAL I/O and ANALOG I/O. Table 4.1 is a list of the number and type of such channels and brief notes about performance. The I/O terminals of the DIGITAL I/O and ANALOG I/O channels are connected to points on the CDAS WIRING PATCH PANEL. Here they are available to be connected to the devices which they must control and from which they must accept inputs. The DIGITAL I/O and ANALOG I/O units were manufactured by Scientific Solutions Inc, 6225 Cochran Rd., Cleveland, OH 44139-3377. Complete manuals and specifications are provided with the equipment.

**ANALOG COMPUTATION COMPONENTS**

Analog operational amplifiers and associated components have been provided for purposes of signal conditioning and minor continuous computation tasks. These components are connected to a small ANALOG PATCH PANEL and via an insertable board, may be interconnected. They may be connected to the other equipment as above via the main CDAS WIRING PATCH PANEL. Standard analog computation techniques are appropriate. A programming manual is provided with the equipment. Table 4.2 is a list of available analog components. Complete manuals for each of the amplifiers are provided with the equipment.

**OTHER HARDWARE**

Other electronic equipment for data collection and control is also available on the CDAS WIRING PATCH PANEL. Among these is a set of RELAYS, ANALOG SWITCHES and ATTENUATORS. These devices are listed and specified in Table 4.2. Complete manuals for each of the devices are provided with the equipment. Space exists for the connection of OTHER INTERNAL EQUIPMENT to the CDAS WIRING PATCH PANEL as needed by a particular experiment. Such additional equipment as signal generators, plotters, measurement devices, etc. fit into this category.

Finally, space exists on the CDAS WIRING PATCH PANEL for the connection of EXTERNAL EQUIPMENT. It is via these connections that the CDAS system is connected to the devices it is intended to control and from which it collects inputs. These devices may either be in the same enclosure as the CDAS system or may be connected via an "umbilical cord" which is wired into the CDAS WIRING PATCH PANEL.

## SOFTWARE

The microprocessor software is the IBM Disk Operating System (DOS) and Microsoft Fortran. Complete manuals are provided with the equipment. The user gains access to the hardware interface units via special subroutines which can be called from Fortran. The hardware interface subroutines were written by Scientific Solutions Inc., 6225 Cochran Rd., Cleveland, OH 44139-3377. The hardware interface routines involve analog and digital input and output as well as timing functions. Full specification and operating instructions for the software are given in the appropriate manuals (supplied with equipment).

In order to use the CDAS, a program must be written in Fortran for each experiment, just as patch panels must be wired for each experiment. The use of Fortran allows great flexibility of function, yet avoids the use of assembly language or special subroutines. The skill in Fortran required is at an intermediate level. Experience in data acquisition and control is helpful. The software manuals provide examples of programs.

TABLE 4.1

HARDWARE INPUT/OUTPUT DEVICES

AVAILABLE FROM THE MICROPROCESSOR

| DEVICE | NUMBER | NOTES |
|---|---|---|
| ANALOG TO DIGITAL CONVERTERS | 32 | 8-bit unit with multiplexer select |
| ANALOG TO DIGITAL CONVERTERS | 16 | 16-bit unit with multiplexer select |
| DIGITAL TO ANALOG CONVERTERS | 16 | 8-bit unit multiplexed. Output sags at rate of 1 bit per 800 ms. |
| DIGITAL TO ANALOG CONVERTERS | 6 | 8-bit units, non-multiplexed. Output holds at set value until reset. |
| DIGITAL INPUTS | 24 | Each bit individually readable or may be read as three 8-bit words. |
| DIGITAL OUTPUTS | 24 | Same as for digital inputs |
| RELAYS | 24 | SPDT, 3A, 100V, reed relays. |

TABLE 4.2

ANALOG COMPUTATION DEVICES AVAILABLE

| DEVICE | NUMBER | NOTES |
|---|---|---|
| OPERATIONAL AMPLIFIERS | 3 | Chopper-stabilized. Burr-Brown model 3354/25. |
| OPERATIONAL AMPLIFIERS | 8 | Utility units. OPAMP Labs model 436 |
| OPERATIONAL AMPLIFIERS | 4 | High-power units. Continuous RMS output of 8W. OPAMP Labs model 434. |
| CAPACITORS | 7 | 0.1 pf, 1% |
| CAPACITORS | 14 | 1.0 pf, 1% |
| CAPACITORS | 7 | 10.0 pf, 1% |
| RESISTORS | | 14 units of each value as follows; 1, 2, 5, 10, 20, 200 kg, 1%, 1/2 W, |
| POTENTIO-METERS | 8 | 10-turn, 50k. Controls on front panel, numeric dials. |

TABLE 4.3

OTHER HARDWARE

AVAILABLE FROM THE CDAS

| DEVICE | NUMBER | NOTES |
|---|---|---|
| RELAYS | 24 | SPDT, 3A, 100V, reed relays. |
| ANALOG SWITCHES | 4 | Four quadrant switches for analog signals - controllable on/off rates. |
| ATTENUATORS | 4 | Programmable analog signal attenuators up to 80 dB in 1 dB steps. |

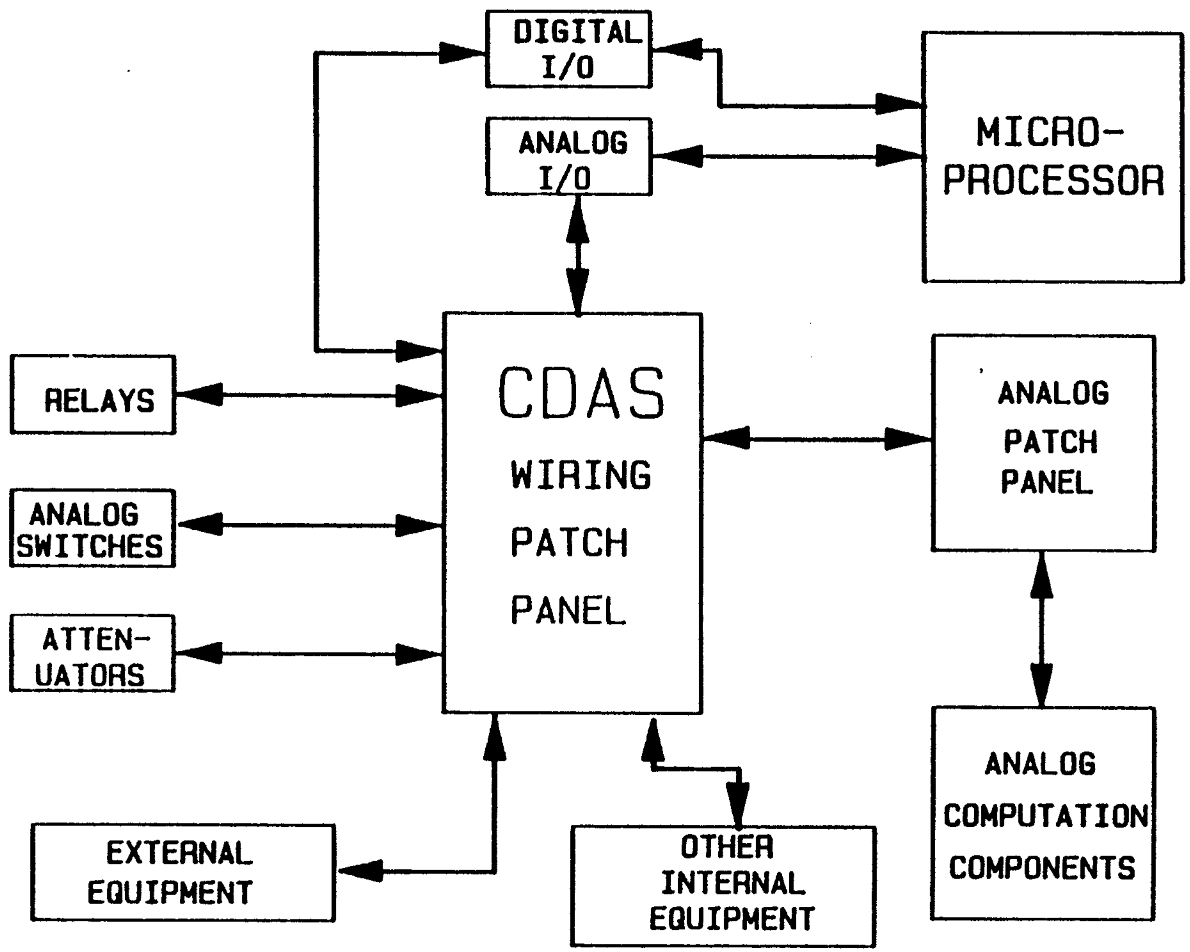


Figure 4.1. Block diagram of the CDAS.

# CHAPTER 5

# MEASUREMENT AND CONTROL HARDWARE

# CHAPTER 5

# MEASUREMENT AND CONTROL HARDWARE

## INTRODUCTION

Hardware was to be specified for the measurement of environmental events and behavior. Hardware had also to be specified to manipulate environmental and stimulus conditions. No actual hardware was to be supplied, however.

Block diagrams of the control and measurement hardware are given in Figures 5.1 and 5.2. The diagrams are flow charts, not wiring or plumbing schematics. In the following discussion, the reader may refer to these block diagrams. The units depicted in the diagrams will be capitalized in the text to aid the reader. The overall block diagrams are to be discussed first and more detailed diagrams of system modules to be discussed later, as appropriate.

## TANK INSTRUMENTATION

Figure 5.1 is an overall block diagram of the hardware for the experimental vehicle (the tank). Both the tank commander and the gunner would be subjects in the experiment. The COMMANDER would be monitored for EEG and for pulmonary function. The EEG HELMET would be fitted and the multiplexed, three-channel signal transmitted to the EEG RECEIVER inside the tank. The PULMONARY FUNCTION would consist of a pneumotachometer and inhaled gas concentration monitor. The GUNNER would also be monitored by a PULMONARY FUNCTION unit whose complexity would depend upon the requirements of the exercise experiment involved. All of the physiological monitoring modules' outputs are fed into a central TELEMETRY INTERFACE.

Breathing gas would be supplied to the subjects via an INHALED GAS CONTROLLER AND SUPPLY module. The controller would receive input from the main gun and would dispense gas of the appropriate composition for the particular condition of the experiment and the number of gun firings. The controller would be set up manually at the beginning of the each experiment to deliver the appropriate gas for the condition to be tested that day. The gas controller would send status signals to the TELEMETRY INTERFACE unit so that the gas conditions would be known at all times. The reason that the gas controller is to be controlled solely from the main gun firing is that there is no available telemetry to the tank from the CDAS.

The TELEMETRY INTERFACE is a system of modules which are to amplify data signals and match impedances to the APG TRANSMITTER which consists of a multichannel RF telemetry system. The choice of channels in the APG TRANSMITTER is open. The RF signals from the APG TRANSMITTER are sent to the receivers in the experiment control station (see below).

The APG COMMUNICATIONS UNIT will be used to transmit routine messages, instructions and test materials (SPIN) to and from the subjects. No modifications to the system are anticipated in order to conduct the experiment. Communications are transmitted by RF signals to and from the experiment control station.

## EXPERIMENT CONTROL STATION

Figure 5.2 is an overall block diagram of the experiment control station. The CDAS receives data from the APG TELEMETRY RECEIVER which receives RF signals from the experimental vehicles. These data include physiological signals and breathing gas status data. The CDAS also receives input from the APG TARGET TRACKING COMPUTER which provides continuous information about target position and main gun tracking error. Lastly, the CDAS receives inputs from the CDAS OPERATOR concerning experiment control and events. This input is to be entered via keyboard. The output of the APG TARGET TRACKING COMPUTER will be the dependent variable in the tracking experiment.

The CDAS provides control output to the APG TARGET CONTROLLER, a target-towing device, so that the target can be positioned according to predetermined schedules. The nature of the control signals awaits the specification of the target-towing device in use at the time of the experiment.

The APG COMMUNICATIONS UNIT is the RF signal system to the experimental vehicle to be used to provide operator communication with the subjects and to send the SPIN test sentences from the SPIN TAPE PLAYER. Control and synchronization of the SPIN TAPE PLAYER with the CDAS would be accomplished manually by the CDAS OPERATOR.

## SUBSYSTEM BLOCK DIAGRAMS

### INHALED GAS CONTROLLER AND SUPPLY

A possible system for control and supply of breathing gas is given in Figure 5.3. The system would use compressed bottled gases (Ci) of known compositions. The cylinders would have two-stage regulators ($P_{Ti}$, $R_i$ and $P_{Ci}$) which would be manually set to give a predetermined pressure. Pressures would be monitored by the CDAS via status lines shown in Figure 5.1. Remotely operated valves, $V_i$, would direct the selected gas into the DOSE RESERVOIR, probably a Douglas bag, from which the subject would breathe. A PUMP and appropriate valving, $V_E$, would empty the reservoir via an EXTERNAL VENT prior to its being filled with the selected test gas. The subject would breathe via flexible tubing attached to his facemask from a valve, $V_S$, which would control his source of breathing gas (AMBIENT, PURGE or one of the mixtures from the bottles, $C_i$. Under either operator or automatic control the experiment would begin with setting and verification of initial conditions. The DOSE RESERVOIR is then to be filled with the first test gas until a predetermined volume is reached. At a predetermined time the subject valve, $V_S$, is to be switched to either AMBIENT, PURGE or to the dose reservoir, depending on initial conditions and the dosing regimen. When the predetermined dose has been given, the subject is to be switched back to AMBIENT or PURGE while the PURGE RESERVOIR is emptied and second dose is filled. The cycle is to be repeated until the end of the experiment.

There are numerous ways that the same functional requirements may be met, e.g., premixed reservoirs of gases may be placed on a common manifold and the subject switched between them or the breathing gas may be mixed 'on line' by a set of mass flow controllers. As the experiment is being designed and the particular vehicle is being selected, the various configurations should be re-evaluated. Among the consideration determining the final design are; number of gas concentration to be used, volume of gas to be inhaled, speed of changes in concentration, extent of automation from the CDAS, amount of status information, amount of humidification, etc.

**OTHER SUBSYSTEMS**

Block or schematic diagrams and specifications for other subsystems shown in Figures 5.1 and 5.2 are given elsewhere in this report (EEG HELMET, Chapter 2 and CDAS, Chapter 4). Other of the units are fully specified elsewhere and depend on the exact equipment in use at the time of execution of the experiment (APG COMMUNICATIONS UNIT, APG TRANSMITTER, TELEMETRY INTERFACE equipment, APG TELEMETRY RECEIVER, SPIN TAPE PLAYER, APG TARGET TRACKING COMPUTER AND APG TARGET CONTROLLER).

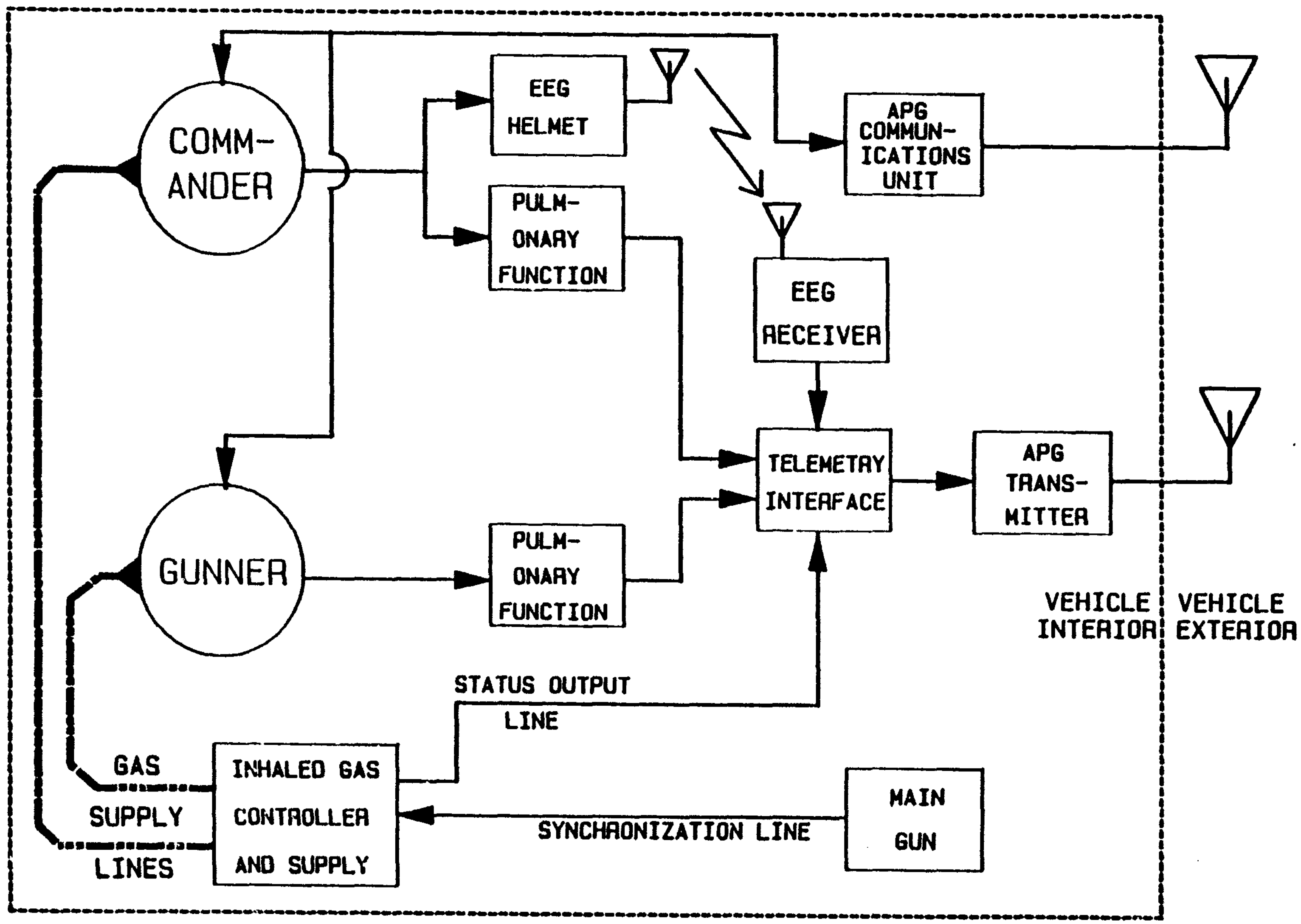


Figure 5.1. Block diagram of control and measurement hardware for the experimental vehicle.

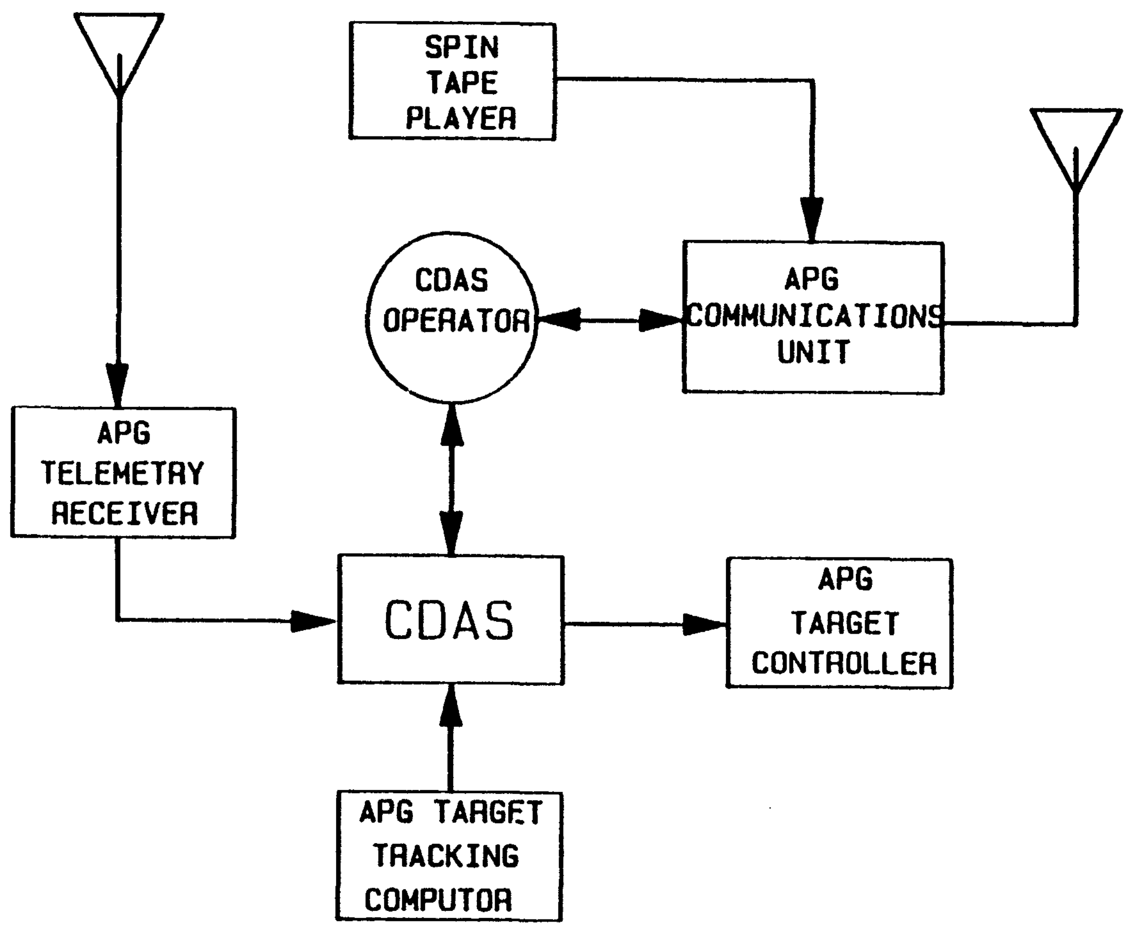


Figure 5.2. Block diagram of experiment control station.

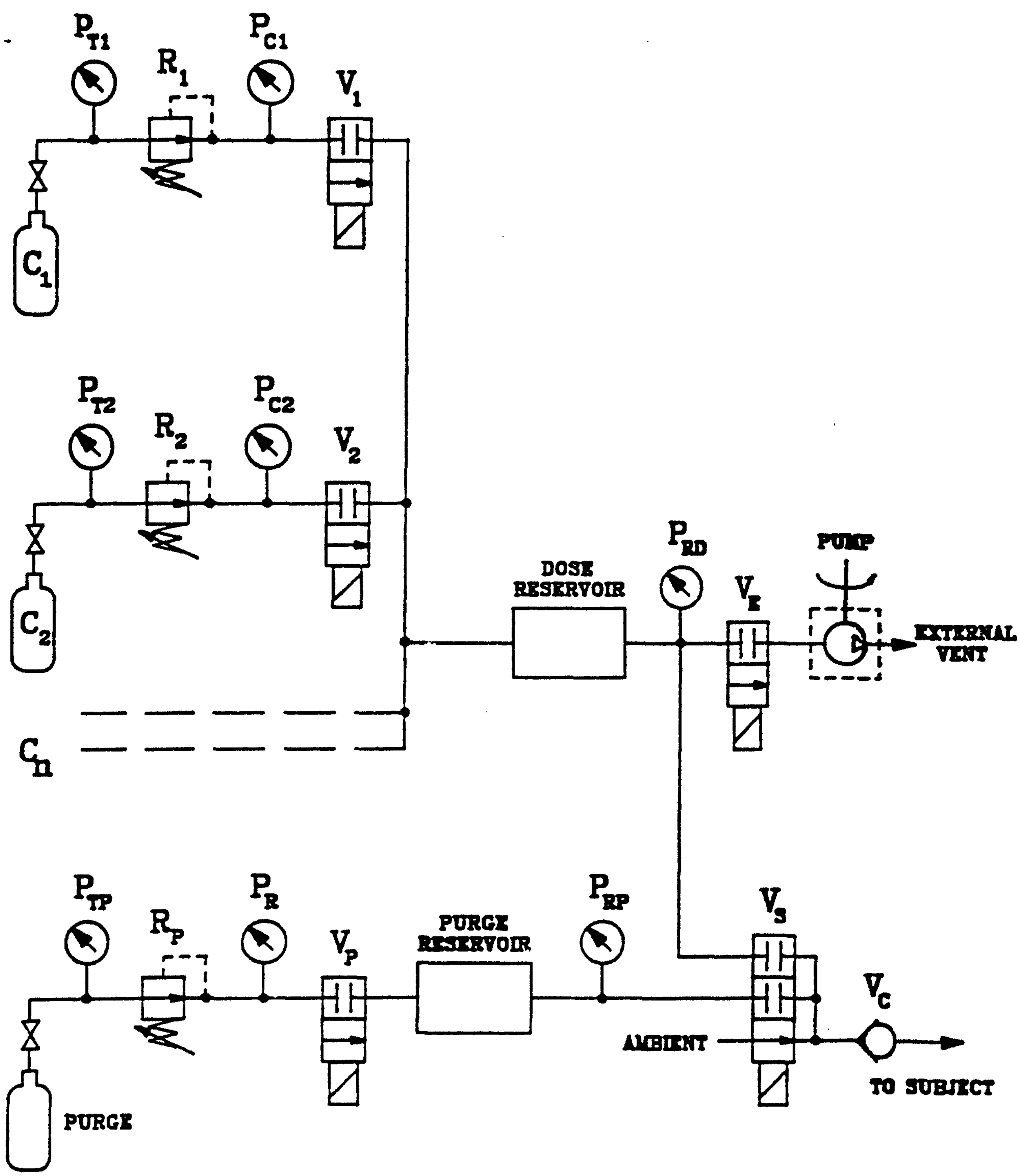


Figure 5.3. Inhaled Gas Controller and Supply.

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