UNDERWATER WORK MEASUREMENT TECHNIQUES: FINAL REPORT

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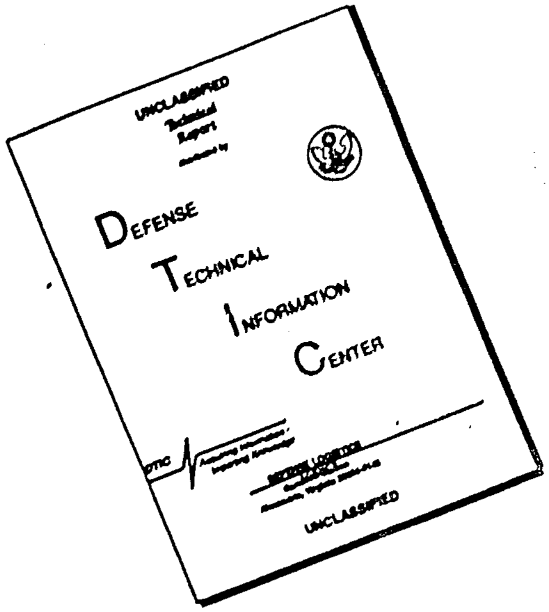

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This is the fourth and last report in a series describing yearly progress of the UCLA Research Project on Optimum Underwater Work Measurement Techniques. The previous reports have covered studies conducted in 1967, 1968 and 1969. This report, in addition to presenting the two major studies carried out in 1970, also provides a summary of work over the four year period. With the cumulative list of project publications, the summary allows the interested reader to identify a topic of concern, determine our primary findings, and, later, explore the topic further in the literature or by reprint request.

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SCHOOL OF ENGINEERING AND APPLIED SCIENCE
UNIVERSITY OF CALIFORNIA
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PREFACE

The research described in this report, "Underwater Work Measurement Techniques: Final Report", was carried on under the direction of Gershon Weltman, Principal Investigator and Glen H. Egstrom, Co-Principal Investigator, in the School of Engineering and Applied Science, University of California, Los Angeles.

This study was supported jointly by the Engineering Psychology Branch (Code 455) of the Office of Naval Research, and by the Bureau of Medicine and Surgery, Department of the Navy.

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Whatever contributions we have been able to make to the methodology of underwater research would not have been possible without the dedicated assistance of our ONR sponsors. Dr. James Miller, former Head of the Engineering Psychology Branch, Washington, D.C., initiated the studies and helped set their direction. Mr. Gerald Malecki has worked with us most helpfully throughout the life of the program. Dr. Martin Tolcott, present Head of the Engineering Psychology Branch, lent his support to this year's efforts. And Dr. Eugene Gloye of the Pasadena Office has taken an active interest in our experiments and results. Appreciation also goes to Dr. Arthur Bachrach, Director of the Behavioral Science Laboratory, Naval Medical Research Institute, for his valuable guidance and many pertinent research suggestions. Finally, we wish to thank all of the other Navy personnel and the UCLA staff and students, who, by serving as subjects and collaborators, have made this program an enjoyable, as well as fruitful, undertaking.

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This is the fourth and last report in a series describing yearly progress of the UCLA Research Project on Optimum Underwater Work Measurement Techniques. The previous reports have covered studies conducted in 1967, 1968 and 1969. This report, in addition to presenting the two major studies carried out in 1970, also provides a summary of work over the four year period. With the cumulative list of project publications, the summary allows the interested reader to identify a topic of concern, determine our primary findings, and, later, explore the topic further in the literature or by reprint request.

II. SUMMARY OF WORK MEASUREMENT STUDIES

INTRODUCTION

This chapter provides a summary of the investigations, findings, and recommendations compiled by the UCLA Underwater Research Group in its study of Optimum Underwater Work Measurement Techniques. The references given appear in the cummulative publications list of Chapter III.

Experimental investigation of diver performance is complicated by a number of factors. In addition to the difficulties which always attend measurement in the field, there is the extra logistics problem of supplying an experimental site underwater, the inherent complications caused by the subject's breathing apparatus and life support gear, and the frequent need for the investigator himself to participate in, and be likewise affected by, the diving activities under examination.

Developing optimum techniques for conducting work measurement studies, in the broad sense, was the objective of the UCLA program. The approach was to examine the applicability of established techniques, select the better, modify them as required, derive new ones where necessary, test and evaluate them in actual underwater experiments, and bring the resulting methodology to the diving research community in the form of project reports and journal publications. Examinations of work measurement techniques was divided into three main areas: (1) work performance per se; (2) the physiological responses that accompany underwater work; and (3) psychological factors that influence work accomplishment. With two additions, General Apparatus and Computer Applications, the following review of topics adheres to this division of interest.

2. METHOD AND APPARATUS

2.1 Underwater Research Facility

Description

The Underwater Research Facility has been a mainstay of experimentation through the study program. Located within the engineering complex at UCLA, it consists of an open 16' diameter by 16' deep bolted steel storage tank fitted with plexiglas viewing ports, electrical pass-throughs, and pipe connections for breathing gas input and output. An instrumentation structure adjoins the tank itself, and provides protection for the apparatus required in specific experiments. Access to the tank is by means of a stairway and platform constructed integral with the instrumentation structure. A half-ton hoist allows experimental apparatus to be easily lifted into and out of the water. Standard pool filtration is provided. An oversized heater and 25-ton refrigeration unit permit exact regulation of tank water temperature between about 40°F and 95°F. Except for paint flaking and rust on the inner surfaces, particularly at the overlap of the bolted plates, maintenance has not been overly time consuming or costly. A variety of paint types failed to endure more than a year; in fact, the more expensive the treatment the less the endurance. (References 6, 7, 8).

Conclusions and Recommendations

a. An open tank of about this size, similarly outfitted, provides a most useful and relatively inexpensive test locale for all but hyperbaric experimentation.

b. For maximum effectiveness, the tank should be made of some non-rusting material If of steel, it should be welded rather than bolted, and a 20' by 20' size would accommodate working teams more comfortably.

2.2 Diving Task Simulation

Description

The UCLA underwater construction task has evolved through several stages to its present form. It is a pipe structure, standing about 7' high on a 4' x 5' base, fabricated of 2" galvanized pipe and correspondingly sized flanges, elbows, valves, etc., with an associated pressure test console containing a bottled gas supply. Two-man diver teams bolt the structure together from preassembled sections stored on the base, inserting open or closed gaskets as required. The resulting pipework is pressurized and tested for leaks, then disassembled and the sections stored again. The "pipe puzzle" requires a diversity of diving skills, including selection and fine manipulation of bolts, nuts, and washers, torquing from various orientations and stabilizations, as well as man-handling and positioning the heavy sections. Teamwork is necessary for efficient completion, and communication between the divers is a requisite for certain task elements. Completion times, errors, and activity analysis are the primary performance measures. Pre-task and post-task written problems have generally been applied in experimental studies to provide an additional measure of cognitive function (References 6, 7, 8, 14, 17, 21).

Conclusions and Recommendations

a. Repeated application in a number of tank and ocean studies has shown the UCLA pipe puzzle task to be readily transportable and conveniently deployed.

b. Diver subjects from novices to professionals and military personnel accept the task because of its scale, its face validity, and its demanding nature.

c. Task performance is sensitive to experience, practice, and environment.

d. The task can be quickly and cheaply duplicated with materials available at any plumbing supply house. (Detailed plans are presented in Appendix I of this report).

e. The UCLA "pipe puzzle" is recommended as a standard perceptual-motor task for underwater assembly. A family of standard tasks should be established to cover all aspects of diver performance.

2.3. Underwater Ergometer

Description

The UCLA ergometer measures fin thrust produced by a diver held in any orientation (but most usually horizontal). The diver swims statically against shoulder bars, and his horizontal thrust is transduced by a load cell attached between the force platform and the fixed base. The load cell output is recorded. It is also averaged electronically and displayed to the diver on a meter mounted on a bracket in front of him. The ergometer has been used to determine the timing and magnitude of instantaneous thrust forces in swimming, in a comparison of fin types, and as a means to vary work load in a study of oxygen uptake underwater. (References 2, 3, 7, 8, 17).

Conclusions and Recommendations

a. Thrusting with fins is a fundamental sustained underwater activity, and forms a more natural basis for ergometry than more artificial tasks such as cranking, weight lifting, etc.

b. Electrical measurement and display of thrust has several important advantages over mechanical means. These include the ability to record instantaneous forces, and to have the subject vary his output rapidly and exactly.

c. Physiological work on such an ergometer is most correctly presented in terms of thrust alone, but by using known relationships between swimmer speed and drag, it can be equated with more commonly used units such as watts, ft-lb/sec, kcal-m/sec, etc.

3. MEASUREMENT OF PERFORMANCE

3.1 Activity Analysis

Activity sampling was used in conjunction with the several phases of the pipe puzzle construction task as one means of evaluating differences in performance among diver groups, or for individual divers under various underwater conditions. Diving activities were defined in specific, job-related terms, such as: "torque bolt", "transport part or tool", "read instructions", etc. The "observe/idle" category encompassed nondemonstrative cognitive activities as well, since it is generally impossible to tell when the diver is thinking, problem solving, recalling, etc. Diver observers and investigators outside the tank were able to assign activities of two-man teams into 9 categories, sampling every 15 seconds, without appreciable error. Errors are more frequent when observation is by television, resolution being the most critical factor (References 6, 14, 2).

Conclusions and Recommendations

a. Activity categories proved relatively sensitive to differences in performance exhibited by novice and experienced divers, for example, or by novices in tank and ocean. For well-chosen categories, the technique adds useful information to basic measures of time and errors.

b. Accurate recording depends on a well-trained observer and a good visual link. For remote viewing by television, careful attention must be paid to system fidelity, camera angle, tank illumination, and diver identification. Initial validation of TV recording against direct recording is recommended where feasible.

3.2 Procedural Recording in the Field

Procedural recording on a large diving job was conducted during the shallow water (50 ft.) trials of the Sealab III Divercon project, which utilized a tethered electrohydraulic lift device to transport and assemble underwater the sections of a large habitat-like structure. The purpose of recording was to permit comparison of the assembly sequence and component times for the 50 ft. and the planned 600 ft. depths. Initial reliance on a single diver-observer proved unsatisfactory, due primarily to the observer's inability to determine, by himself, the purpose of observed activity, and accordingly, its relation to the current assembly scenario. The eventual work observation system centered on a topside station, where incoming information from the operations center, from diver control, from underwater TV, and from the diver-observer was combined to form a complete picture of what was happening and when (References 4, 5, 14, 15).

Conclusions and Recommendations

a. The observer team should understand thoroughly the technical aspects of the diving job in order to follow the scenario through its inevitable changes.

b. As much as possible, macro and micro task elements should be identified before the operation begins. Micro-elements which take about three minutes to complete are the shortest practicable. Macro-elements will vary with the job, but will generally occupy 15 to 100 minutes.

c. Responsibility for decision making resides with the topside member of the observation team. If there is a diver-observer, he is told to watch for landmark events and report when they occur; interrogation is also useful. Narrative reports by the diver are counterproductive.

d. Diving experience is more important than technical knowledge in the diver observer. The usefulness of his communication will be proportional to his familiarity with the depth and conditions of the dive.

3.3 Diving Questionnaires

Description

Diving questionnaires were used in the Sealab III study to extract from the experienced divers their ideas of the human factors important to the project, in a manner amenable to statistical analysis. Two types of questionnaire were used: (1) a trouble shooting check list, which required the divers to estimate the degree of difficulty associated with 10 specific task elements, and to check appropriate items from among 12 possible reasons for difficulty; and (2) forced choice ranking forms, which required the divers to rank in order of difficulty the same 10 factors, and to rank in order of importance to the task at hand 10 generalized diving factors. Both the Divercon and salvage teams were queried (References 14, 15).

Conclusions and Recommendations

a. Despite the intense aversion of divers to paperwork, cooperation can be obtained if forms are kept short and the questions obviously relevant, and if the divers are prepared by prior explanation of aims.

b. On the whole, better results were achieved with the ranking forms. These, although unfamiliar to the divers, yielded significant values of concordance and test-retest reliability, and discriminated well between diver groups.

c. Forced choice froms should be pretested, and revised if necessary, to insure that the choices offered are meaningful to the divers as well as to the experimenter.

3.4 Effects of Environment and Experience

Description

Two studies examined diver performance on the pipe puzzle task and on written problems in the tank and in the open ocean. The first study involved two subject groups: novices and experienced divers. Ideal conditions were maintained in the tank (80°F), while the ocean test site was relatively shallow (20 ft), clear, and not unduly cold (62°F). The second study utilized experienced divers only: performance was compared between a more demanding ocean environment (50 ft., 55-60°F, poor visibility) and the tank cooled and clouded to match the ocean. Results indicated that novice divers performed slower than the experienced divers in the tank, and showed a marked decrement in both assembly time and problem-solving accuracy in the ocean, most likely due to psychological factors. Diving motor skills, rather than work strategy, differentiated the groups. Experienced divers always showed about the same task completion times in tank and ocean. However, there was a tendency to hurry judgemental portions such as pressurization, and to perform less well on problem solving in the ocean environment. (References 14, 17, 21, 22).

Conclusions and Recommendations

a. Design or evaluation studies carried out in the ocean must use subjects highly experienced under those conditions. The responses of inexperienced subjects are markedly different and potentially misleading.

b. For subjects highly familiar with the conditions, there seems to be no significant "ocean effect" for perceptual-motor tasks. Accordingly, tank simulations, equated for temperature and visibility, are efficient and economical experimental environments.

c. Decision-making and problem-solving in the ocean remain open questions, even for experienced divers. This implies a psychological effect even at moderate depths, and suggests that work measurement include these factors whenever practicable.

d. The tendency to perform less deliberately under stressful ocean conditions should guide the observer to look for and record errors, omissions, etc., as well as performance time itself.

e. The ocean decrement of novice divers could be a criterion of training effectiveness. That is, one test of new training techniques would be: Does it reduce the decrement?

f. These findings reinforce the need for the establishment of underwater observor reliability and remote observation backup for underwater data gathering.

3.5 Effects of Water Temperature

Description

A tank study using experienced divers compared pipe puzzle assembly and problem solving at 44°F to performance previously observed at 60°F and 80°F water temperatures. Manipulative operations such as assembly and dissassembly were lengthened by the cold, while other task portions, such as pressurization and problem solving, were shortened. University subjects, experienced in solving similar written problems, showed negligible effect of cold on problem accuracy. Police and professional divers, on the other hand, showed a marked decrease in accuracy from the beginning to the end of the approximately 45 minute runs. (Reference this report).

Conclusions and Recommendations

a. Decreasing water temperature does not invariably lengthen perceptual-motor task performance. Performance measurement should separate the task into "compressible" and "incompressible" components to obtain a true picture of diver adaptation.

b. Cold water may contribute additional degradation in decision-making and problem-solving to those otherwise associated with stressful diving conditions. This is accentuated for prolonged exposure, and for divers generally unpracticed in such tasks.

3.6 Performance Baselines

Description

Diver work measurement is concerned primarily with the question: "How well is the individual or team doing under these specific conditions?" The immediate corollary is: "Compared to what?" Our viewpoint is that the comparison should be with how well the job can be accomplished under ideal diving conditions. This means clear, still, comfortable water, and a minimum of protective gear. It is patently impossible to transfer all underwater work to dry land, and at any rate, the means of doing work is uniquely different underwater. Thus, comparisons with surface performance tend only to perpetuate the common fault of considering diving tasks as familiar tasks done underwater. Such an approach is counterproductive to the analysis and improvement of underwater work skills, and confuses the issue of actual decrements. Surface comparison may be useful in describing and understanding physiological and psychological response to the underwater environment, its use in such studies should be clearly defined and circumscribed.

Conclusions and Recommendations

a. Task performance under "ideal diving" conditions is the only valid reference baseline for work measurement in more adverse environments.

b. Investigators measuring diver work performance should include in their study data on the same task taken under ideal conditions.

c. Since baseline comparisons are not always practicable in field work, a "reference library" of diving standards should be established for well-defined, realistic task components. A partial estimate of baseline performance, at least, could then be constructed by combining equivalent task elements.

4. MEASUREMENT OF PHYSIOLOGICAL RESPONSE

4.1 Measurement System

Description

Physiological measurement at UCLA has focused on a set of basic variables: heart rate, respiratory rate, inspiratory minute volume, and deep body temperature. These are usually recorded as follows. Diver subjects breath from a bottled compressed air supply. Inspiratory air flow is measured by a laminar flow element and associated differential pressure transducer placed in the 135 psig input line of a standard, single-hose regulator. Flow is integrated by operational amplifier over one-minute intervals to provide a sequential record of minute volume. (Volume is corrected for depth.) Respiration rate is derived from the integrated signal by counting the "steps" in each one-minute segment. Electrocardiographic (ECG) signals are detected by water-proofed silver/silver chloride electrodes, connected by 100 ft or more of shielded cable to a high input impedance preamplifier. Deep body temperature is obtained from thin and relatively flexible rectal thermister probes. Continuous records are made on a multi-channel strip chart recorder, and are reduced manually after a run. This system has been operated at the tank for one and two divers, and in the field (pier and shipboard) for one diver. It is currently being converted to tape recording and computer data analysis (see Section 6.2). Heart rate has also been measured by ultrasonic telemetry using a commercial voice communicator. (References 6, 9, 14, 17).

Conclusions and Recommendations

a. The basic physiological variables, recorded by hardwire, have proved reliable in a number of experimental situations. They provide information on all three major compensatory mechanisms, cardiovascular, respiratory, and thermoregulatory, and thus constitute a logical "nuclear" set for underwater work measurement.

b. Diver acceptance of bioinstrumentation has generally been high, if adequate explaination of aims is provided. The rectal probe is a possible exception: although one-time use has not been a problem, repeated application to military or professional divers would likely lead to eventual lack of cooperation.

c. If the divers are on umbilicals, as in most actual work situations, hardwire physiological recording does not interfere with normal movement. Where lines are unrealistic or dangerous, telemetry provides the best monitoring means.

4.2 Basic Physiological Response

Description

In the initial study, subjects in the tank were administered a battery of various surface and underwater tasks, including standarized exercise and self-paced work. Heart rate underwater ranged from 45 beats/min to about 180 beats/min. Respiratory response covered a range of from 0.1 ft^3/min to 2.8 ft^3/min for inspiratory volume, and from about 4 breaths/min to over 25 breaths/min for rate. Response underwater corresponded well to response on the surface, although there was a tendency to observe lower heart rates for physically equal underwater work. Using heart rate and inspiratory minute volume, it was possible to order with some consistancy surface and underwater tasks of known relative workload. Subsequent observations on experienced divers in the ocean for the same tasks showed similar levels for the physiological variables. And divers working on actual construction jobs exhibited nearly the same range of physiological response. It has been possible in these cases as well to correlate physiological response with known demands of the diving task. (References 6, 11, 22, 24).

Conclusions and Recommendations

a. Basic physiological measurements taken during diving operations permit reasonable estimates of imposed workload as "light", "moderate" and "heavy."

b. Physiological response underwater is influenced by several unique environmental and experential factors, depressed heart rate and "skip breathing" being cases in point. More accurate indirect determination of workload depends on further research to deliniate these relationships.

4.3 Correlations Among Physiological Measures

Description

Rank correlation analysis was applied to the results of the study outlined above to determine how consistant were subject responses over the various tests, and how well the several measures correlated on a particular test. It was found that in general, a subject having a relatively low heart rate or minute volume on one test also tended to rank low in these variables on other tests. Correlations were particularly high in the surface-surface case, and, for heart rate, between surface tests and heavy underwater exercise. For the individual subject, the results indicated that while the three physiological measures were closely interrelated, heart rate and minute volume were most highly correlated, while minute volume and respiration rate were least highly correlated. Separate analysis indicated that respiration rate was the least sensitive measure, and that minute volume showed more variability than heart rate for moderate workloads. (references 6, 8, 11, 12).

Conclusions and Recommendations

a. Assuming that the relative level of physiological response is a valid measure of capacity in a particular task, it appears feasible to estimate underwater work capacity through surface tests.

b. Where a choice must be made among physiological variables, heart rate is preferable for underwater work measurement. It has low variability, is easy to obtain, and correlates well with other variables, including oxygen consumption (as discussed below).

4.4 Oxygen Uptake

Description

A brief study was conducted in the UCLA tank to examine the correlation between oxygen uptake and heart rate during underwater swimming. Subjects swam statically in the ergometer at three thrust levels, 9 lbs, 12 lbs, and 15 lbs, corresponding roughly to relaxed, moderate, and strenuous effort. Expired gas was collected through a special exhalation regulator, which permits direct exhalation to one atmosphere of pressure. The results indicated that both oxygen consumption and heart rate increase linearly with thrust. Moreover, the observed ratio of oxygen consumption to heart rate (about 40 beats/min for each 1.0 liter/min O_2) was the same as that previously reported for threadmill work on the surface and arm exercise underwater (References 17, 22, 24).

Conclusions and Recommendations

a. Preliminary analysis indicates that heart rate is a good index of swimming work underwater. More detailed studies examining depth, water temperature, and other work types are required before this relationship can be reliably quantified.

b. Collection of exhaled gas is a reasonable method of determining oxygen consumption for tank studies. Major problem areas are exhalation resistance and CO_2 absorption by moisture in the exhaust lines.

c. Swimming thrust appears to be a diving equivalent of walking and should be adopted as a standard measure of underwater exercise.

4.5 Effects of Water Temperature

Description

Heart rate, respiration rate, inspiratory minute volume, and rectal temperature were measured continuously as experienced divers rested and exercised (pipe puzzle assembly and block moving) at 44°F in the UCLA tank. Deep body temperature dropped steadily over the 45 to 60 minute exposures. Decrease was more rapid during the light assembly task than during rest. Apparently, increased blood flow to the periphery, with consequent blood cooling, more than offset the increased metabolism. Higher exercise levels attenuated this heat loss. Heart rate and inspiratory minute volume during the assembly task were greater at 44°F than previously observed at 60°F and 80°F; the difference increased as exposure lengthened. (Reference this report).

Conclusions and Recommendations

a. Results of this study indicate an increase in the physiological cost of work with decreases in water temperature.

b. The data also suggests a loss of normal voluntary control over respiration for prolonged cold exposure. This may be an additional reflection of the narrowing in attention previously associated with stressful environments.

c. Prediction of work tolerance is particularly critical at reduced body temperatures. Additional information is required regarding physical as well as mental capabilities under these conditions.

3.6 Stress and the Physiological Indices

Description

In the UCLA studies, heart rate and the respiratory parameters have been applied at times to estimate physical effort, and at other times as indicators of psychological stress. Such dual utilization is common in the literature; it is rare, however, to find it in the same investigation. Unfortunately, diving nearly always combines physical effort with some degree of arousal or anxiety. Both of these factors are important to underwater work measurement; and it is therefore incumbent upon the investigator to try and separate them in his analysis. Our experience has provided some guides to this process. (References 4, 5, 11, 14, 15, 23).

Conclusions and Recommendations

a. Baselines of physiological response should be obtained for experimental tasks in a clear, comfortable, safe underwater environment.

b. Elevated heart rate and respiratory response is more likely to indicate anxiety under non-baseline diving conditions when: (1) it is more pronounced in less experienced divers; (2) it decreases with exposure rather than increases; (3) it is not correlated with improved performance times or outputs.

c. Independent psychological or biochemical tests of stress should be applied whenever feasible to confirm the cardio-respiratory indications. A questionnaire test for anxiety is described in Section 4.4.

5. MEASUREMENT OF PSYCHOLOGICAL RESPONSE

5.1 Perceptual Narrowing

Description

Two experimental studies examined the effect on visual perception of the type of diffuse risk-stress generally associated with diving. The first followed a group of novice divers through surface, tank and ocean exposures. Subjects monitored a peripheral light alone, or while simultaneously performing an attention-demanding visual task. On the surface, the central task had no effect on peripheral vigilance. During diving, a identifiable subgroup of subjects showed markedly increased response times to the peripheral lights, suggesting that diving risk also causes the perceptual narrowing previously seen in other stressful situations. This hypothesis was investigated in a more carefully controlled study on dry land: the object was to demonstrate narrowing under similar psychological stress without associated physiological change. A nonfunctioning altitude chamber was refurbished to resemble a high pressure facility; descent to 60 ft was simulated realistically by means of hissing air, moving pressure gauges, etc. The central task was a self-paced automatic presentation of Landolt ring targets; detection of a light flash in the diving mask periphery was the criterion of narrowing. Anxiety was measured by heart rate and a questionnaire. Two groups participated; one in the chamber, the other as controls outside. Central task performance was the same for both groups; but the chamber subjects detected significantly fewer peripheral lights. The chamber group showed a significantly higher heart rate, while the anxiety test scores indicated a normal state for the controls, and "mild" anxiety for the chamber subjects. It was concluded that the results validated the hypothesis. (References 4, 23).

Conclusions and Recommendations

a. Detection of peripheral lights is a sensitive indicator of shifts in attention. Preferably, the lights should be bilaterally presented, at short, random-appearing intervals, and in the same field location for each subject.

b. Diffuse anxiety associated with risky undertakings, like diving, can cause a marked reduction in peripheral attention.

c. Planning of practical diving tasks should include the possibility that the diver's functional vision, already constricted by his mask, will be further constricted during periods of stress.

d. Future research should focus on the quantification of the narrowing effect, its actual influence on performance, its suspectibility to training, and its use to estimate immediate ability to perform.

5.2 Visual Adaptation

Description

A series of tank and pool studies was conducted to investigate how divers adapt to the distortion of object size and distance caused by underwater viewing through a facemask. Size estimates obtained by adjusting a line to an estimated length of 12 in. indicated that upon entry to the water, novices experienced more size enlargement than experienced divers (Experienced divers were also more accurate when viewing through a porthole, indicating the effect was not "situation contingent"). Experienced divers reported objects as closer underwater than they actually were. Adaptation during underwater exposure was demonstrated to size but not to distance. In fact, a negative correlation between size and distance adaptation scores indicated that most divers adapted to one dimension by counteradapting to the other. That is, some subjects improved their judgments of size by degrading their judgments of distance and some the other way around. (References 10, 16, 18, 19).

Conclusions and Recommendations

a. Overall diving experience is probably the main determinant of perceptual accuracy underwater. During a dive, judgment of object size improves more than judgment of distance, but the effect is poorly predictable and not significant practically.

b. For most divers, adaptation to size and distance distortion does not normally occur simultaneously. The negative correlation should be considered when attempting to train divers to improve both aspects of perception.

c. Classical methods of measuring visual adaptation can be applied successfully underwater.

5.3 Diver Personality

Description

One hundred and forty seven UCLA diver trainees were given the Pensacola Z-Survey of personal autonomy. Findings revealed that the student divers described themselves as individualistically as did astronauts and Antarctic scientists, but not significantly more so than did other campus groups. Moreover, the Z-Scale did not differentiate between successful trainees and dropouts, although there was a weak relationship between autonomy and high performance scores during pool testing. Individuals of exceptionally low or exceptionally high autonomy were less likely to be good performers. These results matched those of a similar study undertaken simultaneously in England by H. Ross. (Reference 13).

Conclusions and Recommendations

a. University diving programs provide a large number of motivated, articulate divers. Many future undersea workers will be drawn from a similar population. Thus, determining any special personality attributes of these people could help greatly in program planning and evaluation.

b. Although the Pensacola Z-survey did not prove particularly fruitful, other tests of personality should be applied to diver groups.

c. All trainees perform about the same on the "all-or-none" criteria of training success, but separate over the long run in their development of diving skills, their ability to handle adverse ocean situations, etc. Accordingly it is more likely that the correlation of personality to performance will increase with diving experience.

5.4 Anxiety Questionnaire

Description

Psychological stress is frequently a significant concommitant of work underwater, and its determination an important part of work measurement. In several UCLA studies, successful use was made of the Multiple Affect Adjective Checklist[1] This is a questionnaire test of anxiety, hostility, and depression, designed specifically to measure the immediate level of those variables in an individual. This test is easy to take and to score, and in our experience, sensitive enough to discriminate reliably mild anxiety from normative response. Other investigators also have applied paper-and-pencil tests of anxiety in experiments involving dangerous exposure (References 17, 23).

[1] Zuckerman, M., and Lubin, B. Manual for the multiple affect adjective checklist. San Diego: Educational and Industrial Testing Service, 1965.

Conclusions and Recommendations

a. The Multiple Affect Adjective Checklist has been demonstrated to measure anxiety induced by risky exposure.

b. The test, or another like it, should be applied as a primary or secondary measure in diving work measurement where psychological stress is a known or suspected factor.

c. Investigators should exchange data on anxiety levels measured for specific diving situations in well-defined subject groups. A data bank of diving stress would aid in predicting performance and identifying anomolous response.

6. COMPUTER TECHNIQUES

6.1 Sealab III Scenario

Description

A computer program was written to permit translation of the Sealab III Operations Scenario from typewritten form to computer storage. Printout was provided in the original format, but at greatly speeded rates. The principal innovation was in the area of scenario modification. Under control of the program, the scenario was modified on the alphanumeric display screen of an interactive computer terminal (TV monitor plus keyboard). The system was working well when cancellation of the Sealab experiment halted work on extensions of the basic program. (Reference 20).

Conclusions and Recommendations

a. Computer storage of event descriptions for a complex and lengthy diving program proved highly efficient in time and storage space.

b. Modifying the events and their timing in an interactive mode was effective, and easily learned by secretarial help.

c. Extension of this approach would permit automatic optimization of the scenario, as well as comparisons between the scenario and the actual procedural record, or between the final scenario and its predecessors.

6.2 Physiological Data Handling

Description

A computer program was developed to reduce automatically records of diver physiological response which had formerly been reduced by hand. Experimental data is first recorded on analog tape at the tank or in the field. This tape is converted to a digital tape, which is fed to the data processing computer. The program derives beat-by-beat heart rate from the digitized ECG signal, calculates breathing rate and volume from the integrated inspiratory flow signal, and logs deep body temperature. Print-outs are provided for 1-minute epochs (six 10-second segments) throughout the run, along with the sum summary report. Two divers are accommodated. (Reference this report).

Conclusions and Recommendations

a. Computer analysis is a fast, economical means of reducing physiological data from diving experiments. It provides data which is more accurate and complete than that from manual techniques.

b. Faster data turn-around permits the experimenter to keep closer control over the investigation, as well as to utilize interim results for validation procedures.

c. Use of a central computer facility and peripheral tape recording brings the potential for computer analysis to a broad variety of studies, in many locales.

d. Extension of the present program would provide on-line safety monitoring at critical dive sites. The advantage of the computer is that it can incorporate more complex safety criteria than can the more usual meter limit alarms.

III. CUMMULATIVE PUBLICATIONS

Following are the publications to date of the UCLA Underwater Research Group during the period of the ONR-sponsored work measurement studies.

1. "Visual Fields of the SCUBA Diver," G. Weltman, R.A. Christianson, G.H. Egstrom, *Human Factors*, Vol. 7, No. 5, pp. 423-430, October 1965. (Published June 1966).

2. "Thrust Forces in Underwater Swimming," R.A. Christianson, G. Weltman, G.H. Egstrom, *Human Factors*, Vol. 7, No. 6, December 1965. (Published August 1966)

3. "A System for Underwater Ergometry," G. Weltman, G. G. Egstrom, R.A. Christianson, *AIAA/USN*, 2nd Marine Systems & ASW Conference, AIAA Paper No. 66-713, Los Angeles-Long Beach, California, pp. 2-24, August 8-10, 1966.

4. "Perceptural Narrowing in Divers: A Preliminary Study," G. Weltman, G.H. Egstrom, R.A. Christianson, UCLA, Department of Engineering, Report No. 66-67, December 1966.

5. "Perceptual Narrowing in Novice Divers," G. Weltman, G. Egstrom, *Human Factors*, Vol. 8, No. 6, December 1966. (Published January 1967).

6. "Underwater Work Measurement Techniques: Initial Studies," G. Weltman, G. H. Egstrom, R.E. Elliott, H.S. Stevenson, Department of Engineering, Report No. 68-11, March 1968.

7. "Assessing Work Performance Underwater," G.H. Egstrom, G. Weltman, *Marine Sciences Instrumentation, Volume 4*, Plenum Press, New York, 1968. Presented at the ISA MArine Sciences Instrumentation Symposium, Cocoa Beach, Florida, 1968.

8. "Measuring Work Effectiveness Underwater", G. Weltman, G.H. Egstrom, *J. of Ocean Technology*, 2(4): 43-47, October, 1968.

9. "Underwater Heart Rate Telemetry Using an Ultrasonic Voice Communication System," G. Weltman, G.H. Egstrom, *J. Aerospace Med.*, 39(12): 1354-5, December, 1968.

10. "Adapation of Divers to Distortions of Size and Distance Underwater," H.E. Ross, S.S. Franklin, G. Weltman, UCLA, Department of Engineering, Report No. 68-61. January, 1969.

11. "Heart Rate and Respiratory Response Correlations in Surface and Underwater Work,' G. Weltman, G.H. Egstrom, *J. Aerospace Med.* 40(5): 479-483, May 1969.

12. "Heart Rate and Respiratory Response Correlations in Surface and Underwater Work (Abstract)," G. Weltman, G.H. Egstrom, *Cardiology Digest* 1969.

13. "Personal Autonomy of SCUBA Diver Trainees," G. Weltman, G.H. Egstrom, *Res. Quarterly*, Vol. 40, No. 3, pp. 613-618. October 1969.

14. "Underwater Work Measurement Techniques: 1968 Studies," G. Weltman, G.H. Egstrom, P.A. Christianson, T.P. Crooks, UCLA, Department of Engineering Report No. 69-19, April 1969.

15. "Diver Performance Measurement for Sealab III," G. Weltman, T. Crooks, G.H. Egstrom, *Underwater Association Report*, London, 1969.

16. "Adaptation of Divers to Size-Distance Distortion Underwater," H.E. Ross, S.S. Franklin, G. Weltman, *Underwater Association Report*, London, 1969.

17. "Underwater Work Measurement Techniques: 1969 Studies," G. Weltman, G.H. Egstrom, T.P. Crooks, R.A. Christianson, UCLA, School of Engineering and Applied Sciences Report No. 7052, July 1970.

18. "Size-Distance Invariance in Perceptual Adaptation," S.S. Franklin, H.E. Ross, G. Weltman, *Psychon. Sci.*, 21(4): 229-231, 1970.

19. "Adaptation of Divers to Size Distortion Underwater," H. Ross, S. Franklin, G. Weltman, P. Lennie, *British J. Psychology*, 61(3): 365-373, 1970.

20. "Computer Handling of the Sealab III Operations Scenario," G. Weltman, H. Golden, *Marine Technology Society Journal*, (4)1: 67-70, 1970.

21. "Effects of Experience and Environment on Underwater Work Performance," G. Weltman, R.C. Christianson, G.H. Egstrom, *Human Factors*, 12(6): 587-598, December 1970.

22. "Human Factors Influencing Underwater Performance," G. Weltman, T. Crooks, *Equipment for the Working Diver: Symposium Proceedings*, Marine Technology Society, Washington, D.C., 1970.

23. "Perceptual Narrowing During Simulated Pressure Chamber Exposure," G. Weltman, E.J. Smith, *Human Factors*, 13(2): 99-108, April 1971.

24. "Diver Work Methods," G. Weltman, *Human Performance in the Sea*, Athletic Institute, Chicago, 1971.

25. "Diving Equipment," G.H. Egstrom, *Human Performance in the Sea*, Athletic Institute, Chicago, 1971.

IV. COMPLEX TASK PERFORMANCE IN COLD WATER

INTRODUCTION

The physiologic mechanisms that come into play during cold water immersion and the variables that affect these mechanisms are of obvious importance to the working diver. The detrimental effect of extremely cold water on underwater work was suggested by Pugh et al. (1960) and Keatinge (1961). Others, Costill et al. (1967), investigating these mechanisms with warmer water temperatures came to the conclusion that water temperature would not significantly alter the metabolic responses of men during submaximal work. Craig and Dvorak (1968) attempted to combine this conflicting testimony into a unified theory relating water temperature to core temperature drop at different work levels. The deleterious effect of low water temperature on work performance has been demonstrated for isolated tests by Bowen (1968), Miller et al. (1969), Stang and Wiener (1970), and others. Intervening variables such as equipment, type of work, etc. have not been well quantified in the literature.

Our aim in the present study was to supply a broader view of the physiologic and performance picture of a diver as he works in cold water on a comprehensive diving task with typical deep diving gear. Our approach was to utilize past experimentation, Weltman, Egstrom et al. (1969, 1970), as a comparison to similar experiments at colder water temperatures. A 25-ton capacity water refrigeration unit added to the UCLA Underwater Research Facility enabled us to reduce water temperature to an average of 44°F. In this environment performance and physiological data were taken on a group of subjects during rest, during construction of a standard pipe assembly task, and also while performing a block-moving task.

2. METHOD

2.1 Assembly Task

Description

The assembly task was the same as that previously used by Weltman, Egstrom, et al. (1969, 1970), for measurement of complex underwater work performance. The structure, shown in detail in Appendix I, consists of four subassemblies and a manifold made of 2 inch diameter galvanized pipe, with appropriate flanges, gaskets, valves, and connectors. It stands about 7 feet high on a 4-foot by 5-foot base. A team of two divers bolt the structure together with appropriate washers and spacers, pressurize it from a gas console, then disassemble it. In order to add a degree of mental reasoning to the task, five diving physics problems were added, three before assembly and two after. The five phases of the construction task were;

1. Pre-Problems. Three written problems requiring the calculation of pressures and volumes as a function of depth were presented before

the assembly of the structure was begun. Each problem required several steps to arrive at the correct answer. Each diver was required to fill in all blanks. He could use mental reasoning alone to solve the problem or he could calculate on any available space on the answer sheet. A typical pre-problem that related to the subsequent task was: "Gauge pressure underwater equals depth in feet times 0.5. This is called "ambient" pressure. The structure leak check pressure is 15 PSI above ambient pressure. At your depth of 15 feet, what should the console gauge read for leak check pressure?____________ What should the console gauge read for sealing pressure?____________." Similar problems were utilized in all runs.

2. Assembly. Three pipe subassemblies and the manifold were bolted to the structure using 1/2-inch nuts and bolts and a specified combination of open and solid gaskets. The pipe sections weighed 39, 44, and 50 lbs. It generally required both members of the team to place and secure each of them. The nuts and bolts were tightened with an adjustable wrench and a torque wrench to 30 ft.-lbs. of tension on each bolt.

3. Dewatering and Pressurization. The assembled portion of the pipe structure was dewatered and pressurized. Both sides of the assembly leading to the manifold were tested independtenly for leaks. Air was introduced into the selected side of the structure by appropriate manifold valves. The air was supplied from a gas console through a hose which the divers connected to the manifold. Once the section had been dewatered, one diver closed the vent valve and the other diver increased the structure air pressure to a specified level. The first diver then reopened the vent and lowered the air pressure to a second specified level. The second side was then dewatered and pressurized by the same procedure. The task always required the coordinated efforts of both divers.

4. Disassembly. The three subassemblies and the manifold were unbolted from the structure and placed within the remaining framework. Nuts and bolts were returned to a container and the gaskets were hung on a wire hook.

5. Post-Problems. The post-problems were identical in nature to the pre-problems, except that two instead of three problems were completed.

2.2 Block Moving

Description

A self-paced block moving task was used to examine the physiological response to a moderate work load. The task was to repetitively move five concrete blocks between a floor-level pallet and a three-foot-high pallet six feet away. The blocks measured 51/2x71/2x151/2 and weighed 39 pounds submerged. The task required use of numerous muscle groups both in the lifting and transport segments. Previous studies, Weltman, Egstrom, et al. (1968), had demonstrated relatively high work levels for this task in the underwater environment.

The block moving task, which lasted for a period of fifteen minutes, was preceded by thirty minutes of precooling. The precooling period required the subject to remain quiet and provided time for recording an approximate physiological baseline with which to compare the work levels of the construction task and the block moving task. After completion of the block moving task, the subject remained in the water for five more minutes while post-exercise data was recorded.

2.3 Personal Equipment

Divers wore full neoprene wetsuits, gloves, and booties for cold protection. Instead of a demand regulator as previously used, the divers wore Kirby-Morgan band masks. This is one of the commonly used underwater work masks, and provides facial protection against cold water. The masks were surface-supplied through umbilical hoses. The Kirby-Morgans permitted two-way communication with the surface, but not between divers. The divers wore fins and a weight belt and were instrumented as described below.

2.4 Performance Recording

Description

Two variables of interest in the diving situation are useful work output, and the quality of that work. Construction task completion times were used as a measure of work output, while assembly errors and problem correctness were used as a rough measure of the quality of diver output. Each diver was provided with a plastic tablet which contained: (1) The pre-problems; (2) brief assembly, dewatering, and disassembly instructions; (3) a diagram of the completed assembly; and (4) the post-problems. Spaces were provided on the tablet for the subject to record his phase completion times and problem answers. The investigators also recorded completion times on the physiological strip chart record (see below). Times were later cross-checked to verify their accuracy. The subjects' problem answers and time data were transferred to subject data sheets immediately upon the completion of each run. The problem answers were later checked for correctness.

The objective of the block moving task was to determine the physiological response to a substantial work load in the underwater work environment. A record was kept of the number of blocks repetitively moved during the 15-minute task period.

2.5 Physiological Recording

Description

Heart rate, minute volume, respiration rate, and rectal temperature measurements were taken on all subjects throughout each run. Body weight was taken pre and post exposure to see if any large weight losses occurred at this water temperature under normal diving conditions.

Both divers wore water-proofed skin electrodes connected to the preamplifiers of a multi-channel strip chart recorder. Inspiratory flow was measured by means of a laminar flow element and associated differential pressure transducer placed in the air supply line. The flow signal was integrated over one-minute intervals using an operational amplier. The amplifier output was then fed into the strip chart recorder. Alternate minute data were obtained for both divers working on the construction task by means of a flow switching device. Data were taken continuously on the subject performing the block moving task. When the data were later reduced, volumes which were measure at atmospheric pressure, were corrected to a depth of eleven feet. Respiration rates were derived by counting the between-breath plateaus on the integrated minute volume recordings.

The difficulties associated with measuring the temperature of the hypothalmus in a submerged, working diver are considerable. While external auditory canal temperature is an excellent measure of core temperature for non-submerged subjects, damming of the ear is risky for divers, because increased water pressure may drive the dam into the sensitive eardrum. We therefore settled on rectal temperatures, a relatively easy measurement, as the best available estimate of core temperatures. A specially-prepared flexible thermistor probe was inserted approximately four inches into the rectum. Data were taken throughout the run. A switching device was used to obtain alternate minute rectal temperatures for each diver during the construction task. Measurement was continuous during the block moving task.

Weight losses were recorded by accurately (0.5oz) weighing the nude subject before and after each experimental session. The subject was weighed after he had voided and before suiting up. He was reweighed after he had thoroughly dried himself with a towel and voided if necessary.

2.6 Experimental Locale

Description

All experimental sessions were carried out at the UCLA Underwater Research Facility. The Facility's operational versatility was expanded with the installation of a Dunham-Bush 25-ton water refrigeration unit. In addition, equipment was added to monitor, by switching, minute volumes and rectal temperature of two divers during experimentation.

Mean Water temperature for both the construction task and the block moving task was 44°F. The range during the construction series was 42-50°F. The high temperature was the result of a one day outage of the unit. The range for the block moving series was 43-45°F. Outside air temperature averaged about 83°F, with a range of 75-94°F.

2.7 Subjects

Description

The subjects for this experiment provided as representative a population as was possible from the diving community available to us. Twenty-five subjects participated in the construction task. They varied in age from

18 to 43 years; their average age was 29 years. Diving experience ranged from 3 months to 16 years, and averaged 31/2 years. Eight subjects participated in the block moving task. They averaged 30 years of age with a range of 22 to 43. Their diving experience varied from 1 to 10 years and also averaged 31/2 years.

The backgrounds of our subjects varied: Some were university students and staff (4), some Los Angeles County sheriffs from the Emergency Services Detail (8), and some were students in a local commercial diving school (15). Three subjects participated in both the construction task and the block moving task.

3. PROCEDURE

Description

For the construction task the twenty-five subjects were formed into two-man teams. Eight teams ran twice and six teams only once. Three members of these six teams participated in two runs. Therefore nineteen subjects participated twice and six participated once. All subjects were given at least one dry run on construction procedures and all questions concerning the task were answered. They were encouraged to discuss their plans and decide which diver would do each task. Signals were prearranged by the subjects since they could not communicate verbally underwater. The subjects were given one or two practice diving physics problems and all had had moving experience with problems of this type. The block moving task involved individual runs. The eight subjects were given brief instructions on procedures. The simplicity of the task provided uniformity.

Upon arrival at the Research Facility the subjects were first briefed. They were then weighed and donned wetsuit bottoms and booties. The rectal thermistors and electrodes were next applied. The subjects finished dressing. When ready they went to the diving platform to put on the Kirby-Morgan helmets and weight belts, and to connect their senor umbilicals. They then entered the water and began the experiment.

4. RESULTS AND DISCUSSION

4.1 Performance in Cold Water

Description

Assembly, dewatering, and disassembly phase completion times for the present cold water series and comparable data from past experimentation at 60°F and 80°F are tabulated in Table IV-1. The eight subjects for the 60°F runs had been diving for an average of 4 years. All had at least 1-1/2 years diving experience. They were given two practice runs. The data listed is the results of the two experimental runs for the nine teams which participated. Five divers who had been diving consistently for at least 2 years were the subjects for the 80°F runs. For a conservative comparison, the data presented for this more comfortable working environment are the first four runs that each of the divers participated in.

TABLE I

Construction Task Phase Completion Times (Minutes)			
	Water Temperature		
Phase	44°F	60°F	80°F
Assembly	24.5	22.7	19.3
Dewatering	5.6	6.7	
Disassembly	10.5	8.9	6.7
Totals	40.6	38.3	26.0

The two completion times of most interest are the assembly and disassembly phases. These task phases are the least compressible. That is, each step in each phase requires the completion of the previous one. Therefore there are no methods other than increased efficiency that will result in their shortening. The extreme hand cooling in the 44°F water necessitated the wearing of neoprene diving gloves, while gloves were worn by only two subjects during the 60°F runs and by none at all during the 80°F runs. The increase in hand insulation most likely offset the expected decrement in manual performance due to cold. It is felt therefore that the initial construction phases, particularly the assembly phase, are somewhat shorter than they otherwise would have been.

The total time required for the assembly and dewatering phases was 10 minutes longer in the 60°F water than in the 80°F exposures. The 44°F subjects wearing gloves required about two minutes longer than the 60°F subjects for assembly. They completed the dewatering phase, however, in less time than the 60°F subjects.

The divers in the 44°F exposures had typically been in the water about 34 minutes by the start of the disassembly phase. Even with the diving gloves, hands were numb and in some instances stinging by this time. The decrements in completion time for the 60°F and the 44°F disassembly phases over the 80°F series were 24% and 57% respectively. The decrement observed in the 44°F exposures over the 60°F runs was on the same order as Bowen (1968) observed in his group assembly task.

The faster problem set and dewatering completion times seen at 44°F corroborated previous findings (Weltman, Egstrom, et al., 1969 and Bowen, 1968) of an apparent speed-up in compressible dive phases as environmental stress increases.

Performance of our subjects on the dive problems in the 44°F water suggested a division of the population into two groups. In the first group were all those subjects who had extensive backgrounds in numerical computation, such as engineers, scientists, and physical science students. The other group consisted of those subjects who did not have this extensive mathematical background, the sheriffs deputies, commercial diving students, etc.

Table IV-2 summarizes performance scores for the two types of subjects in water of three temperatures. Although all subjects were instructed on the method for solving the problems and were given example problems prior to the dive, the group that did not have numerical background performed quite poorly throughout, and showed a consistent decrease in accuracy from pre to post task testing. The "mathematical" group, on the other hand, was not uniformly affected even by the 44°F exposure.

It is concluded that for those individuals well practiced in solving written problems, water temperature will not cause significant decrements in performance. However, subjective reports of extreme difficulty in concentration on the task at hand suggests an increased cost of maintaining normal mental performance in cold water. This finding is in agreement with Bowen's report of "cold water environmental distraction" associated with tasks requiring the use of short-term memory, on which our "non-mathematical" subjects perhaps had to rely on almost entirely.

TABLE IV-2

Dive Problem Performance (Percent Correct)

	Water Temperature					
	44°F		60°F		80°F	
Subjects	Pre	Post	Pre	Post	Pre	Post
University Divers	80	90	92	79	90	93
Regular Divers	39	24	63	21	--	--

4.2 Work Level and Physiological Response

Description

Heart rate, minute volume, and respiration rates for the five phases of the construction task are presented in Table IV-3. Similar data for the block moving task is presented in Table IV-4. The data reflect the difference in work levels. During the 30-minute pre-colling period heart rate averaged 86 beats/min, while during the construction task the average was never under 103 beats/min. The block moving phase was obviously more stressful than any period during the construction task, with heart rate averaging 123 beats/min during this period. On the average the subjects moved 2,106 pounds (54 blocks) from the low pallet to the high pallet and back again during the fifteen minutes of this phase.

TABLE IV-3
SUMMARY OF CARDIO-RESPIRATORY DATA
DURING CONSTRUCTION TASKS

(N=25)

Phase	Heart Rate (Beat/Minute)			Minute Volume (Liters)			Respiratory Rate (Breaths/Minute)		
	High	Ave	Low	High	Ave	Low	High	Ave	Low
Pre-Problems	146	107	76	36	21	11	31	17	7
Assembly	150	114	94	38	27	17	28	19	9
DeWater	142	107	83	44	29	19	32	19	9
Dissassembly	144	113	89	46	31	20	32	20	10
Post-Problems	129	103	76	49	29.7	20	32	19	9

TABLE IV-4
SUMMARY OF CARDIO-RESPIRATORY DATA
DURING BLOCK MOVING

(N=8)

Phase	Heart Rate (Beats/Minute)			Minute Volume (Liters)			Respiration Rate (Breaths/Minute)		
	High	Ave	Low	High	Ave	Low	High	Ave	Low
Pre-Cooling	104	86	78	22	14	9	13	8	6
Block Moving	150	122	110	43	34	24	25	16	12
Post-Cooling	121	89	73	30	24	18	18	12	5

Average rectal temperatures for the first 40 minutes of the construction task and the block moving are presented in Figure IV-1. Only runs lasting 40 minutes or more are included in the averages to prevent shifts due to the loss of data points. During the activity of the construction task rectal temperatures initially dropped slightly, while during the rest period (30 minutes) before block moving they did not. Craig and Dvorak (1968) observed similar results in warmer water. Even with the neoprene diving suits adding insulation, light exercise produced larger falls in rectal temperatures than rest. This is consistent with the view held by Keatinge (1961), Pugh and his coworkers (1955, 1960), and Craig and Dvorak (1968) that the increase in extremity blood flow accompanging exercise causes increases in body heat loss that are larger than the heat produced by that exercise. The moderate exercise of the block moving produced a slower fall in rectal temperatures than did the less strenous construction task. This suggests that light exercise is the worst situation for core temperature loss in cold water.

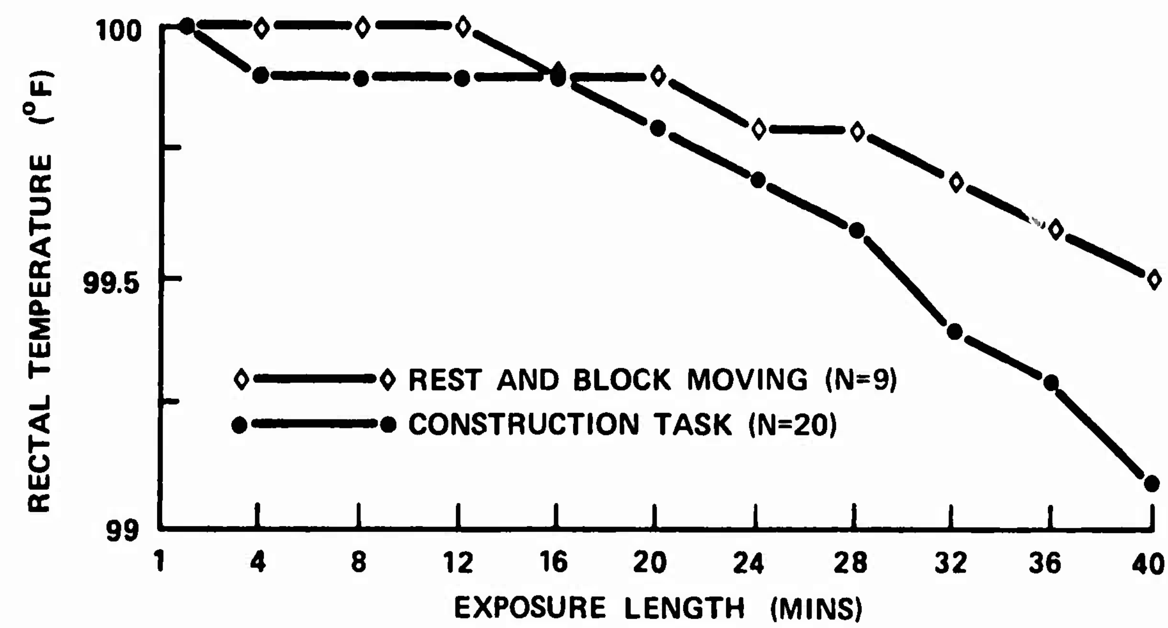

Figure IV-1. **Average Rectal Temperatures During Cold Water Exposure**

The sudden increase in work level after chilling encountered in the block moving task resulted in three subjects reporting nausea during and after the block moving phase. One subject felt nauseous for two hours after the exposure. These subjective reports emphasize the stress produced by the combination of cold and heavy exercise.

Weight loss for the eight subjects who participated in the block moving averaged 7.4 ounces, and ranged from 0 to 20 ounces. For the construction task it averaged 6.9 ounces, varying from 3 to 15 ounces. These small weight losses were felt to be more a result of sweating on the surface than to any diuresis that could have developed during the exposures.

4.3 Water Temperature and Physiological Response

Description

Phase-by-phase environmental comparison for heart rates during the construction task are presented in Table IV-5, the same data are plotted in Figure IV-2. Heart rate increased as water temperature decreased for all five phases, and the similarity in response patterns is striking. It is felt that the initial increase, particularly in the pre-problems and the beginning of the assembly phase, may be due to a cold-induced reflex such as Keatinge et al (1964) found in his subjects suddenly subjected to cold showers. As the period of exposure continues the increased heart rates are probably maintained by increased metabolism. In earlier work Keatinge and Evans (1961) found similar increases in their nude subjects resting in water at about the same temperatures. At water temperature of 95°F and higher they observed increasing heart rates. Craig and Dvorak (1968, 1969) observed that this increase started at slightly lower water temperatures, when the subjects increased their work output. Moore et al. (1970) working at water temperatures of from 61 to 86°F saw minimum heart rates at 72°F at rest and low work levels and at 61°F at higher work levels.

TABLE IV-5
HEART RATES DURING CONSTRUCTION TASK AT DIFFERENT WATER TEMPERATURES

Phase	Heart Rate (Beats/Minute)		
	44°F (N=25)	60°F (N=8)	80°F (N=15)
Pre-Problems	107.5	92.2	78.3
Assembly	114.2	107.5	91.3
Dewatering	107.8	99.3	81.3
Disassembly	113.9	107.5	86.7
Post-Problems	103.7	93.2	75.7

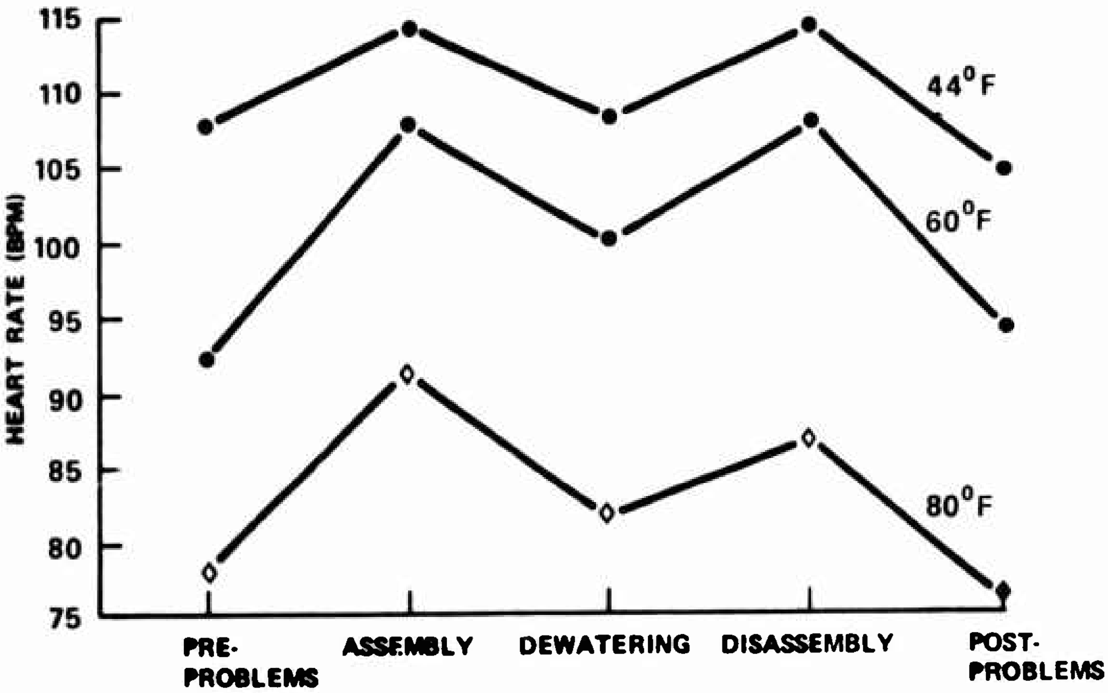

Figure IV-2. Heart Rates During Construction Task at Different Water Temperatures

Costill et al. (1967) on the other hand, observed no significant change in heart rate with water temperature. However, his subjects were exercising at work levels necessitating 3 liters of oxygen per minute and heart rates near 150. This high work rate effectively masked any differences present.

Minute volumes and respiration rates for 44°F and 80°F runs are presented in Table IV-6 and Figure IV-3. The respiration monitoring equipment described in this report was not used during the 60°F exposures because the initial intent of those runs did not necessitate exact measurements. Scuba tank pressure drops were used as a rough indicator of air consumption, but this method is not sufficiently accurate for our present comparision. Therefore that data is omitted.

The minute volumes and respiration rates in all phases increased from the 80°F runs to the 44°F runs. Like the initial increase in heart rate, the initial increase in respiration is felt to be reflex in nature. Keatinge and Nadel (1965) support this reflex hypotheses. They further reported that their subjects could not voluntarily control their breathing during the beginning of ice-cold showers, which ould present an added danger to a diver in an emergency situation in cold water. As the length of the exposure continues, increased metabolism undoubtedly contributes to the increases in respiration. Craig and Dvorak (1968, 1969) reported increased oxygen consumption in resting and exercising individuals with decreases in water temperature. Moore et al. (1970) observed lower ventilation rates in their subjects in 86°F water than was seen in 72°F and 61°F water for all work rates. Costill et al. (1967) similarly observed increased ventilation rates in 63°F water over 80°F exposures.

TABLE IV-6
RESPIRATORY RESPONSE DURING CONSTRUCTION TASK
AT DIFFERENT WATER TEMPERATURES

Phase	Water Temperature			
	44°F (N=25)		80°F (N=15)	
	Minute Volume (Liters)	Respiration Rate (BPM)	Minute Volume (Liters)	Respiration Rate (BPM)
Pre-Problems	21.1	16.9	17.0	10.3
Assembly	27.2	18.9	24.3	12.3
Dewatering	28.7	19.2	20.7	11.3
Disassembly	31.1	20.4	21.7	12.3
Post-Problems	29.7	19.4	19.3	11.3

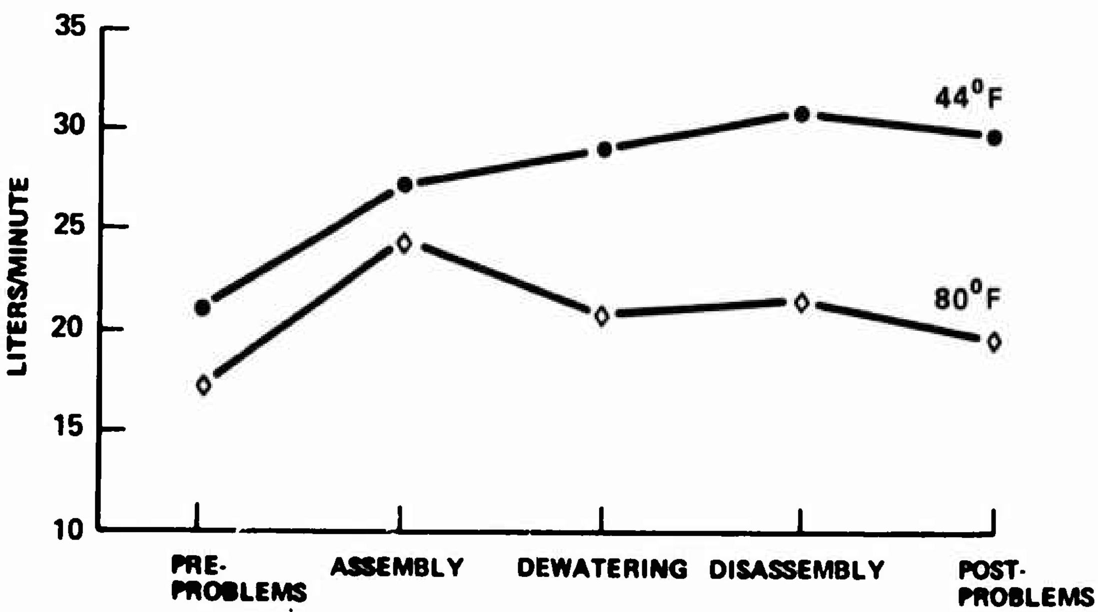

Figure IV-3. Minute Volumes During Construction Task at Different Water Temperatures

Graphical presentation of the heart rate and ventilation rate data indicates that there must also be another factor involved. Figure IV-2 demonstrates a realtively constant increment in heart rate throughout the exposures. Figure IV-3 shows that the increase in ventilation rates become larger as the exposure lengthened. Minute volumes during the pre-problems were 4 liters/minute larger in the 44°F series than in the 30°F runs. The difference had increased to 10 liters/minute by the post-problems.

Examination of Keatinge and Evan's data (1961) reveals similar differences between water temperatures. If the increase in ventilation was due solely to increased metabolism, these increases should be matched by corresponding increases in heart rates. It is hypothesized that as the duration of the exposure continues, the diver is more highly stressed, both physiologically and psychologically. Increasing stress results in an inability to control respiration. During the initial stages of exposure the divers often controlled their respiration to lessen interference with the task at hand. Thus when a diver is attempting to thread a nut on a bolt, he may suppress his breathing momentarily. The small difference in minute volumes during the assembly phase supports this observation. As exposure lengthens and his stress load increases, the diver must channel more of his attention to the central task and less to those that are secondary. Diminished control over secondary phenomena is manifested in increased respiration. This hypothesis is an extension of the concept of perceptual narrowing on task performance (Weltman, Egstrom et al. 1969) to include psychological control of respiration.

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V. COMPUTER HANDLING OF PHYSIOLOGICAL DATA FROM DIVERS

INTRODUCTION

1.1 Background

Description

Measurement of diving work performance at the UCLA Underwater Research Facility has depended heavily on physiological data. The physiological recording systems used at the facility and in the field have been described fully elsewhere, and are reviewed only briefly below.

Electrocardiographic (ECG) signals are recorded by means of waterproofed electrodes connected by shielded cable to a high-input impedance amplifier. Inspiratory air flow is measured by a differential pressure transducer located across a laminar flow element in the diver's air line. Flow is integrated by an operational amplifier to give consecutive minute volume. Recently, temperature measurement from rectal probes has been added to the bioinstrumentation system. Generally, the three basic parameters -- ECG, inspiratory minute volume, and deep body temperature -- are measured for two divers simultaneously over runs typically one hour long.

To date, physiological measurement, whether at the Facility or in the field, has yielded continuous strip charts on which are recorded the various parameters for each particular run. Figure V-1 is a sample record, showing the parameters and their range of values. Strip chart recording is not unusual for such experimentation. However, manual reduction of these paper records has occupied a considerable number of man-hours over the past few years, and yields at best partial information.

An automatic on-line data recording and reduction system was developed as a means of improving these procedures. The system takes advantage of a standard computer facility and of magnetic data recording techniques for obtaining fast and efficient data analysis. Among the advantages of this approach are the following:

- The need for manual data handling and reduction is eliminated.
- Whenever further computer analysis is required there is no need for additional card punching or other manual data entry.
- The accuracy of the experimental data improves.
- Larger amounts of data can be reduced in shorter time -- the experimenters are provided with the possibility for early identification of sensitive test parameters.

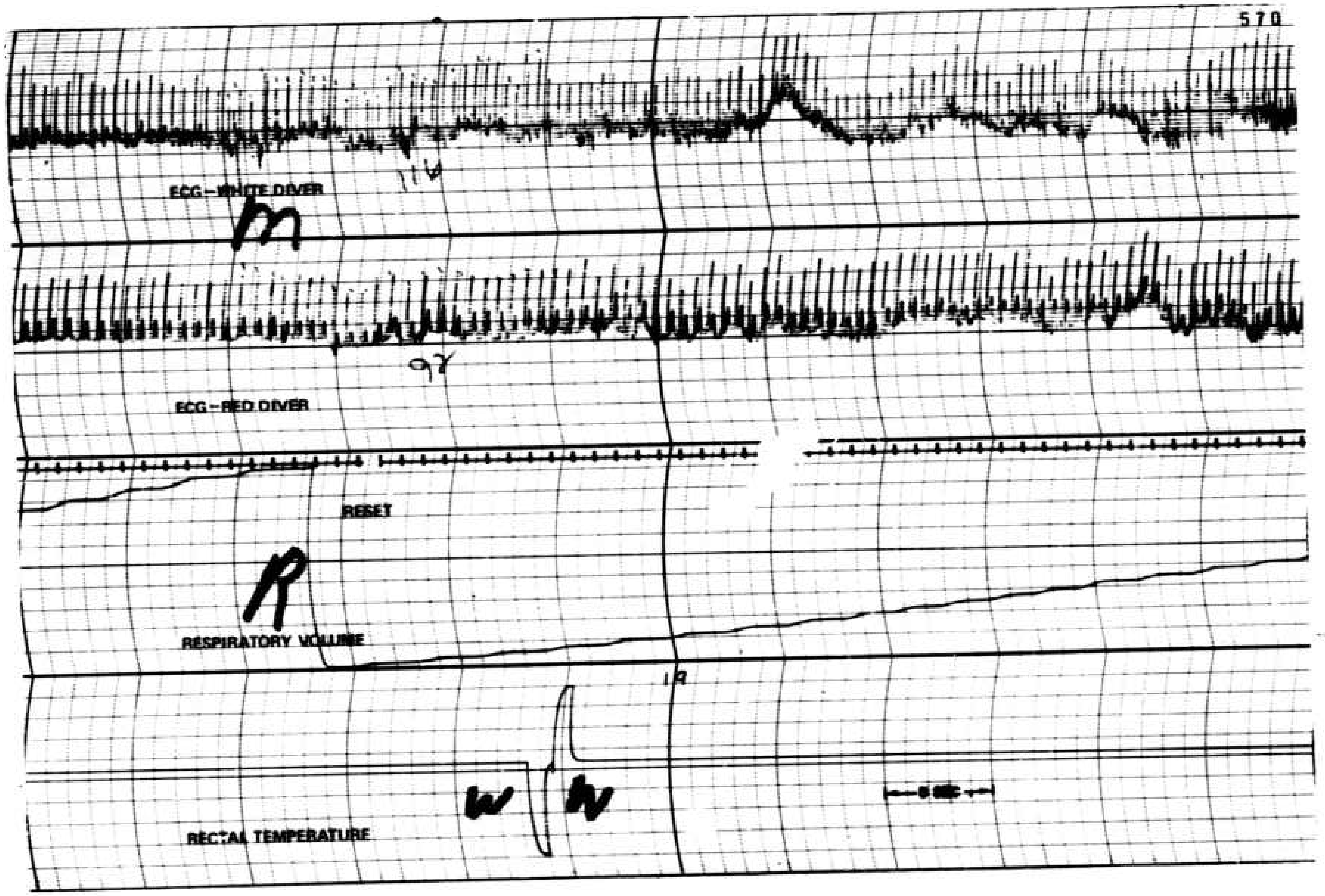


Figure V-1. Sample Physiological Recording

- The system takes advantage of standard computer facilities and multichannel analog recording technique--no special purpose hardware is required.

- The system generates organized and ordered summaries of the physiological data in the form of printed reports and graphical plots.

1.2 System Concept

Decription

Figure V-2 illustrates schematically the system concept. On-line computer analysis of the physiological data is performed in three phases. The first phase is the experimental run, where data is acquired by the bioinstrumentation system and recorded on an FM-FM tape recorder. The second phase is analog to digital conversion, where the recorded analog data is converted to a computer compatible digital tape. Digital tape provides a means for direct data transfer to the computer facility (an IBM 360/90 computer is available on the UCLA campus). In the third phase the experimental data is processed, and summary reports and graphical plots are generated. The program is stored on cards and entered in to the computer before processing. In later versions, program modifications might also be made by means of interactive terminal.

2. THE COMPUTER PROGRAM

2.1 General Organization

Description

The general organization of the program is shown in Figure V-3. Starting from the top of the figure, the program reads in a record of one minute of digitized data samples. The data is then organized in core for processing. Heart rate and minute volume values are calculated. A report image is formulated and a one-minute report is printed. The above process continues until all the experimental data is processed. The following sections of this chapter provide detailed descriptions for the heart rate, minute volume, and summary report subprograms.

2.2 ECG/Heart Rate Analysis

Description

The function of the ECG program is to automatically and continuously extract heart rate information from a digitized ECG signal, on a beat-to-beat basis. Digital samples of the ECG signal are recorded on a digital tape. Beat-to-beat heart rate is derived from the measured interval between successive 'R' waves. Thus the fundamental processing task is to recognize with certainty that an 'R' wave has occurred in the digital data record.

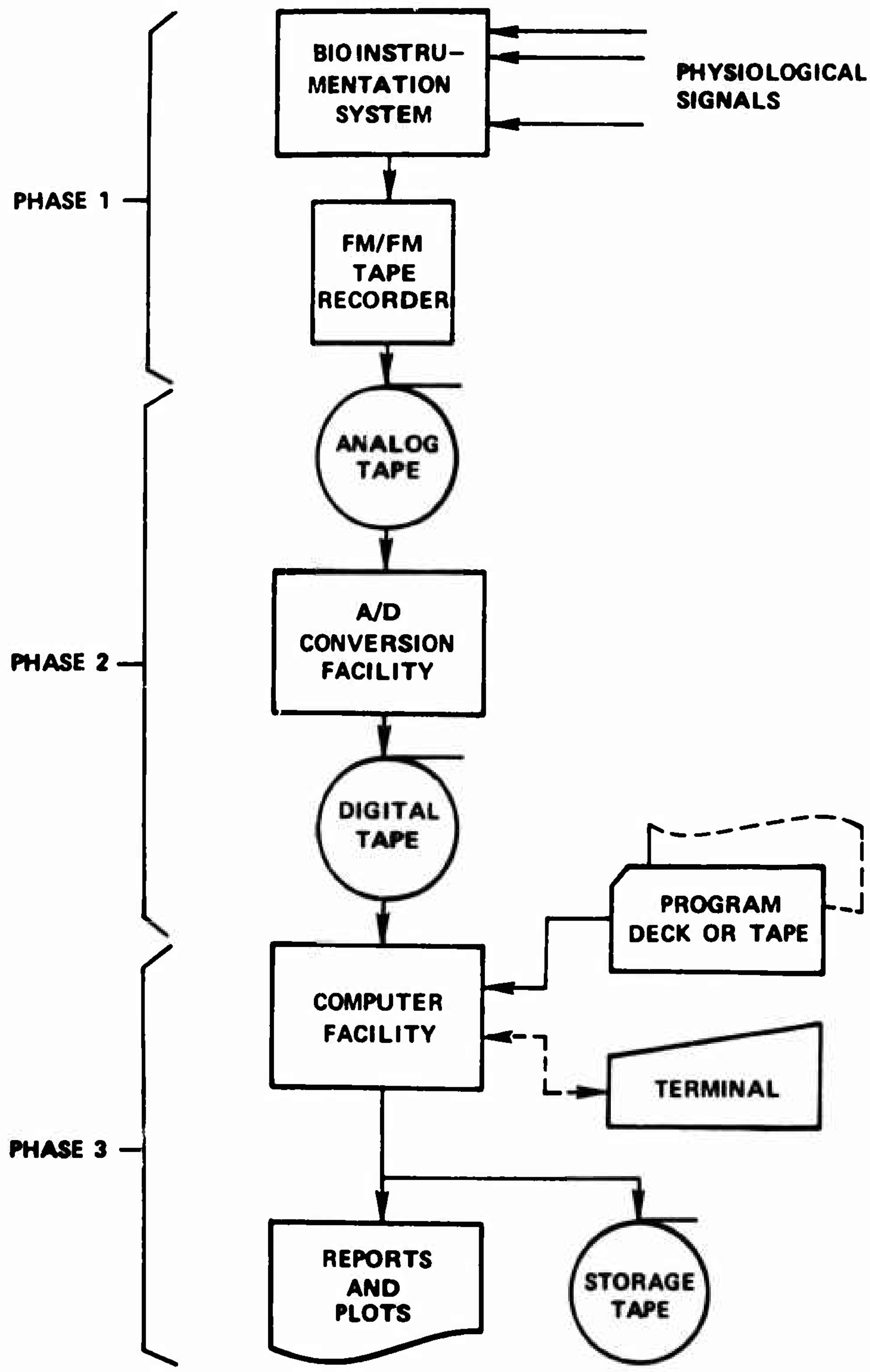


Figure V-2. The Physiological Data Processing System

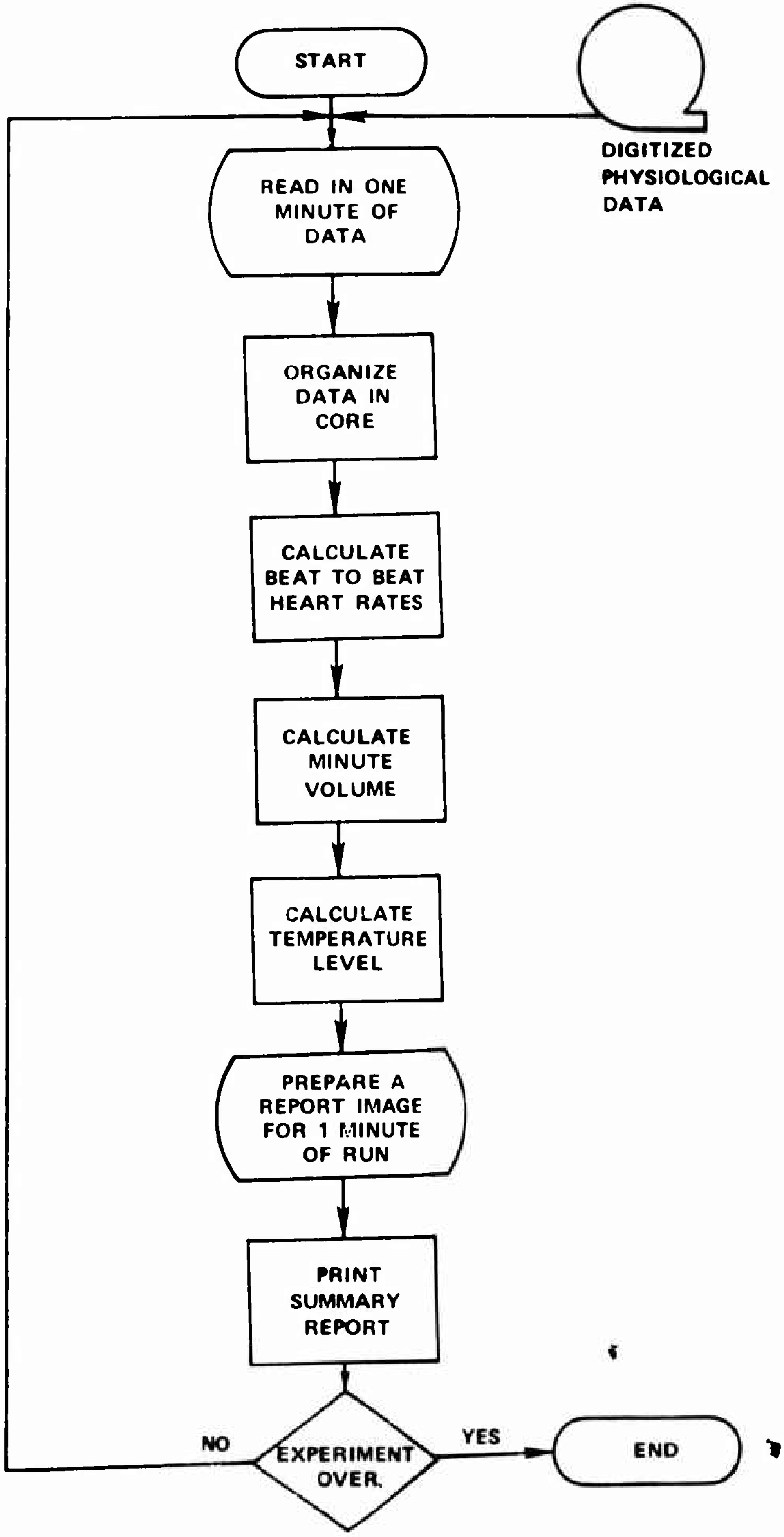


Figure V-3. Physiological Data Analysis Program

The approach adopted is based on one first used by Caceres and his group at HEW, Washington, D.C. The technique rests on using the derivative of the ECG signal, rather than the raw signal itself, as the basic reference. Differentiation eliminates most of the problems associated with trying to apply strict amplitude-threshold criteria to a complex, multiphasic, variable amplitude waveform.

Figure V-4 illustrates a typical ECG signal (continuous processing includes the following steps (see Appendix II):

- The incoming signal is digitized at the rate of 240 samples/sec.

- The differentiated waveform is obtained by computing the slope DV(I) as follows:

  DV(I) = V(I+4)-V(I) where V(I) is the ECG signal level at the I^{th} sample.

- An initial 2-second segment of waveform (which contains at least one QRS complex) is selected for examination.

- The greatest negative value of the derivative is located and established as a reference point. (This usually occurs on the descending portion of the 'R' wave.)

- The threshold limit value is established for determining equivalent reference points on succeeding complexes. The threshold is maximum negative derivative value plus one-sixth the range between the maximum negative and maximum positive values and can be written as:

  REF=DV(I)MIN + (1/6DV(I)MAX - DV(I)MIN)

- A positive threshold value is established for determining a lower acceptable limit for the positive derivative POSR. This limit is determined as:

  POSR = D(I) MAX + 1/6 (DV(I) MAX - DV(I) MIN)

- The presence of an 'R' wave is checked for by sensing that a maximum positive derivative of sufficient value (e.g. 9.38 mV/sec) has occurred within a fixed interval (e.g. 128 msec) before the reference point. (This shows that the sharpest wave in the complex was positive going, and that it was sufficiently sharp to be an 'R' wave). If an 'R' wave is present its peak is located at the point of maximum amplitude in the ECG signal within about 64 msec before the reference point.

- The next 'R' wave is found by applying the above rules each time a potential reference point occurs. (negative derivative below threshold.) R-R intervals are measured by counting the number of samples between

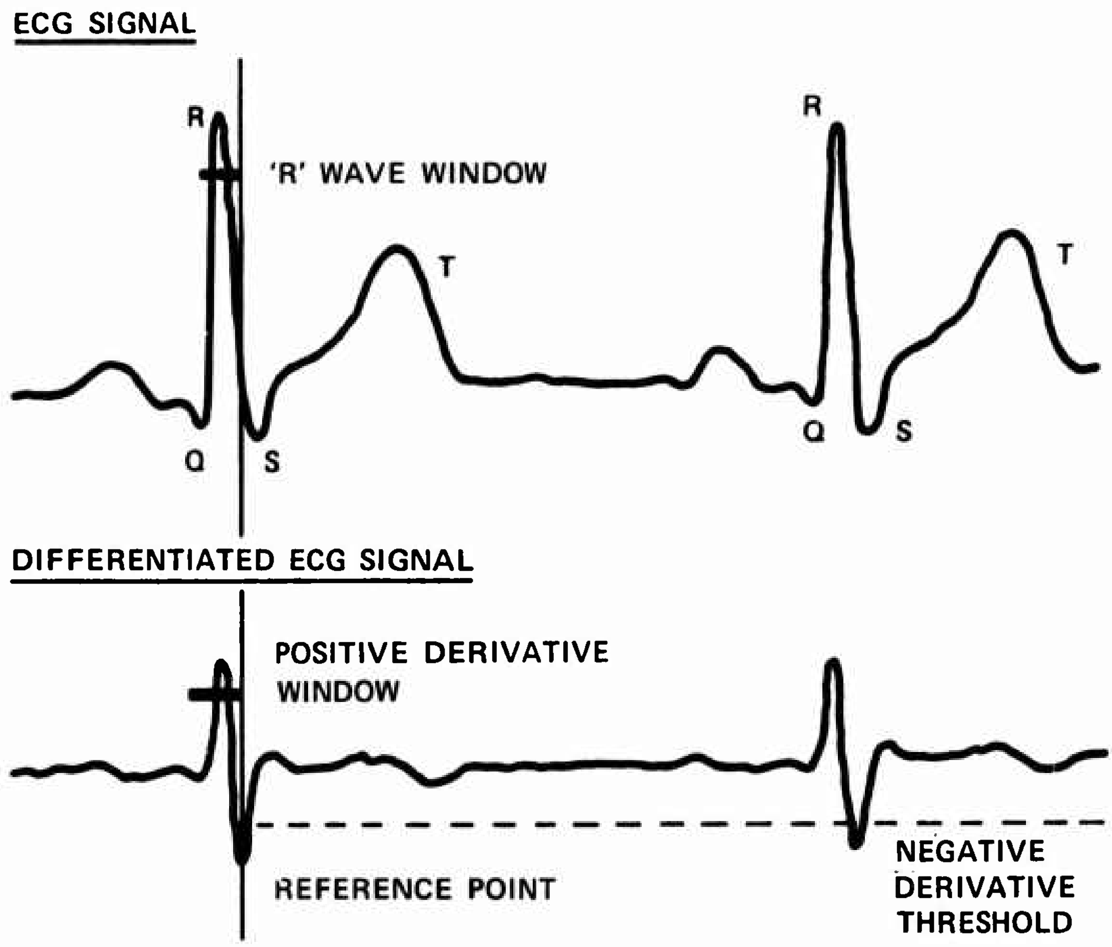


Figure V-4 Typical Waveforms in EGG Heart Rate Processing

'R' waves, or by using internal timing information. Beat-by-beat heart rate is obtained by taking the reciprocal of the R-R interval.

- The heart rate within each 10 second interval is calculated by averaging the Beat-to-Beat rates which occur over this period.

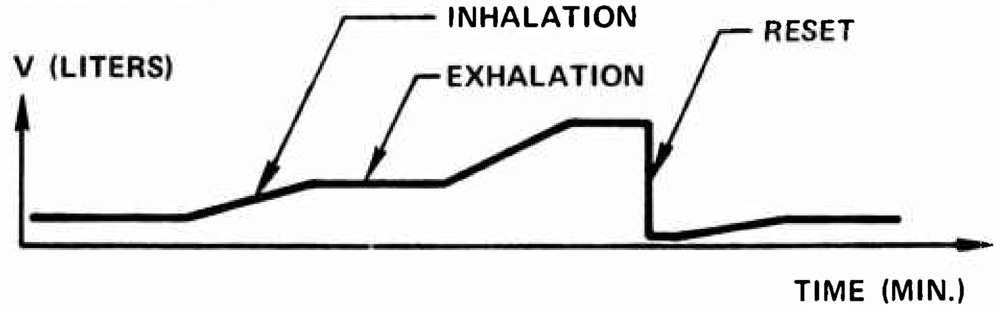
- A one minute mean heart rate is calculated each minute by averaging six consecutive 10-second heart rate means.

- As noisy data occurs, it is deleted from the process by the program. That is, when an 'R' wave determination cannot be made, the program ignores that interval and goes on to the next. The missing data do not influence the statistical averages.

2.3 Minute Volume Program

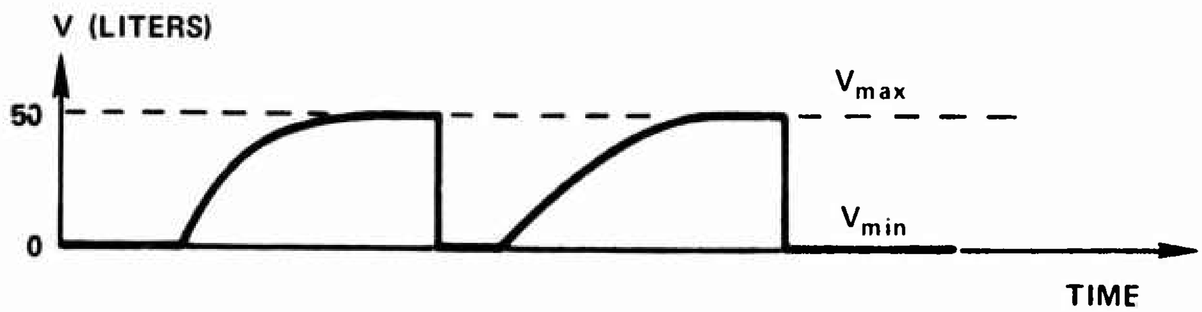
Description

The object of the Minute Volume Program is to analyse the integrated respiratory waveform in order to compute the volume of air (in liters) that the working diver inhales each minute. The typical minute volume waveform appears as follows:



The ramps correspond to inspiration while the plateaus reflect the expiratory phase of the respiratory cycle. In order to measure the amount of air inspired each minute, the program must compute the amplitude of the waveform just before it is reset to the zero baseline.

Due to variations in the recording equipment, the program was also designed to perform a calibration procedure. Each minute volume run begins with a calibration (cal) signal. This cal signal sets up in the program the lower baseline leve (V_{min}) and upper values corresponding to the full range of minute volume, (V_{max}). The following is a typical cal signal.



The program converts digitized data readings into the appropriate air volume measurements. The program was also designed to filter out inaccurate data caused by free-flow leakages of air. This is done by checking rate of change for the integrated minute volume. If invalid data is evident (rate of change to high) the entire method is discarded, and the program proceeds to the following minute segment.

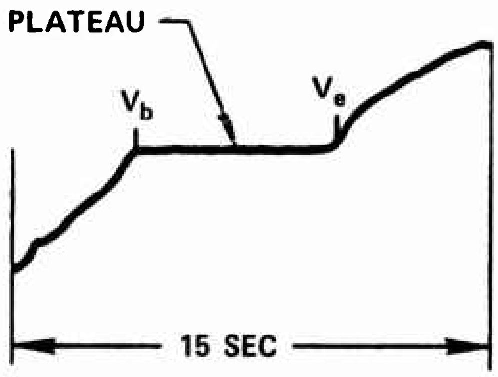
The operation of the program can be followed from the flow chart of Figure V-5, and is summarized as follows:

- The program first detects the calibration signal. This is done by checking whether the slope of the signal exceeds a present threshold.

- Minimum and maximum calibration signal levels are read by the program and a calibration constant, K_V, is calculated as follows:

$$K_V = \frac{50}{V_{max} - V_{min}} \quad \text{liters/volt}$$

- The program checks for the beginning test run data and checks whether free flow exists. The rate of change of the signal occurring within the first 15 seconds of run is calculated in order to detect a plateau, as shown below:



V_b and V_e are determined. Free flow exists if $(V_e - V_b)$ where is the free flow slope threshold.

- If free flow exists, the program deletes the 1 minute segment of data containing free flow volume value.

- If the data are valid, the program reads the amplitude at the end of 1 minute and calculates the volume as follows:

$$V = V_{AM} \times K_V$$

- The above procedure is repeated with subsequent 1 minute data segments.

Although the program does not presently do so, it is planned to use the internal identification of inhalation to determine respiratory rate for each 1 minute interval.

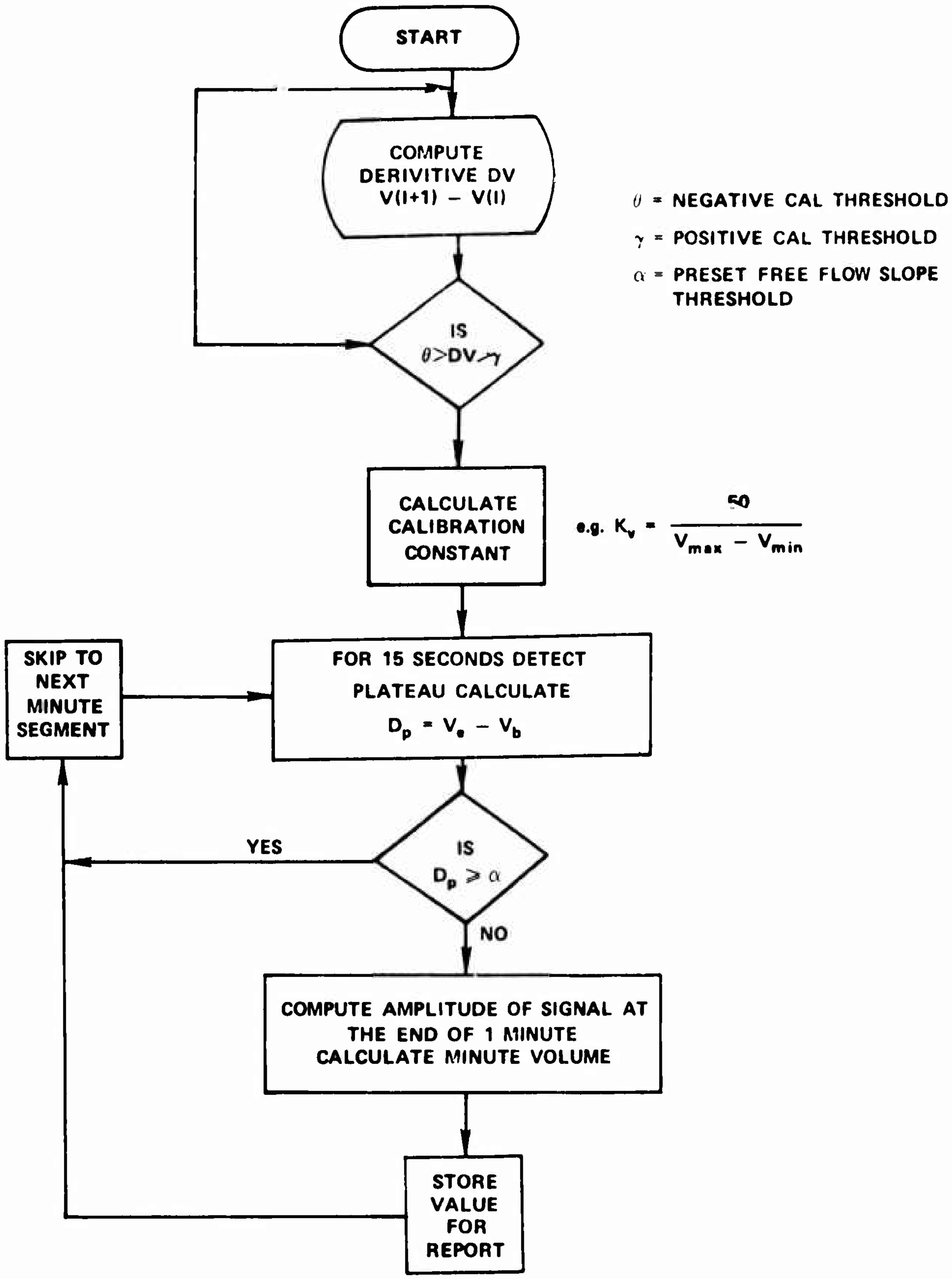


Figure V-5. Minute Volume Program

2.3 Core Temperature Program

Description

The function of the core temperature program is to calibrate the data and calculate the average temperature level in each 1 minute interval. Calibration is performed the same as in the minute volume program, i.e., a calibration constant K_T of ^oF/Volt is established. Data is sampled every 10 seconds and a one minute average is computed every six samples.

2.4 Analysis Report and Graphical Plots

Description

The basic analysis report consists of a 1 minute time line presentation of the processed data. Each one minute of data makes up a page in the report. An example of a page is shown in Figure V-6. The report contains physiological data from two divers. There are three basic columns for each diver which are: Heart rate, Minute Volume and Cor Temperature. Each line of the report represents data of a 10-second time interval of experimental run. The Heart Rate represents a 10-second mean of the beat-by-beat mean. The 10-second Minute Volume value represents the integrated value to that point. A minute-by-minute summary is produced at the run end.

As an option the program can also produce graphical plots of experimental data as a function of time. The graph is generated by a CalComp plotter which is driven by the IBM 360/91 computer.

The Y-axis of the plot represents the heart rate values obtained by averaging the beat-to-beat rate over pre-set time segments. The X-axis represents the time scale. The time scale can be selected according to the range of time selected. The main value of the graphical data plot is to enhance visualization of trends and relative variations in the physiological parameters.

3. CONCLUSIONS

The computer analysis program provides an automated procedure for physiological data reduction and summary. Aside from eliminating the need for excessive manual work, it offers accuracy and elegance in data analysis and presentation in the form of printed reports and graphical plots. The compatability of the system with an FM/FM analog tape provides an option for remote data recording. A compact tape recorder can record data at remote experimental locations such as boats or other diving platforms. The recorded tape can be then shipped to the computer facility for data analysis.

Tests of the physiological analysis program have demonstrated the capability of the program to calculate heart rate and minute volume adquately and efficiently from real data. The cost of running the program was found acceptable and deeper then manual work. Costs can be further reduced to about a quarter by a minor modification in the organization of the program.

MINUTE BY MINUTE DATA

MINUTE 10

	WHITE DIVER			RED DIVER		
TIME (SECONDS)	HEARTRATE (BEATS/MINUTE)	MINUTE VOLUME (LITERS)	CORE TEMP (DEGREES F)	HEARTRATE (BEATS/MINUTE)	MINUTE VOLUME (LITERS)	CORE TEMP (DEGREES F)
0:10	79.1	1.9	99.6	85.7	[illegible]	99.2
10:20	77.7	4.2	99.6	82.3	[illegible]	99.2
20:30	77.4	6.1	99.5	80.1	[illegible]	99.2
30:40	75.4	8.7	99.5	[illegible]	11.[illegible]	99.2
40:50	70.7	10.1	99.5	88.5	14.5	99.2
50:60	76.7	12.3	99.5	87.4	[illegible]	99.2
MEAN	76.2	12.3	99.5	85.1	[illegible]	99.2
MAXIMUM	79.1	12.3	99.6	[illegible]	[illegible]	99.2
MINIMUM	70.7	12.3	99.5	[illegible]	[illegible]	99.2

COMMENTS:

(20) TIGHTENING NUTS AND BOLTS

Figure V-6. Sample Computer Report for 10th Minute of Typical Experimental Run

As tested, the program actually consisted of a set of separate subroutines which had to be called each time the beat-to-beat heart rate was calculated. Linkage of the subroutines into a single large program, as shown in the flowchart will reduce the processing time significantly.

Since the program was coded in Fortran IV it is compatible with most computers as well as with the general class of mini-computers. This feature provides the possibility of running the program at other computer centers. In addition, the program could also be used in an on-line, real-time, mode to perform safety monitoring of divers while they perform underwater work tasks. In such applications the program will run on a dedicated mini-computer equipped with a continuous output display to indicate the physiological state of the divers. Such a display could be in the form of digital meters, or of an CRT screen. Since the UCLA facility has ordered a minicomputer it will be possible to apply the program to continuous monitoring in the near future.

APPENDIX I

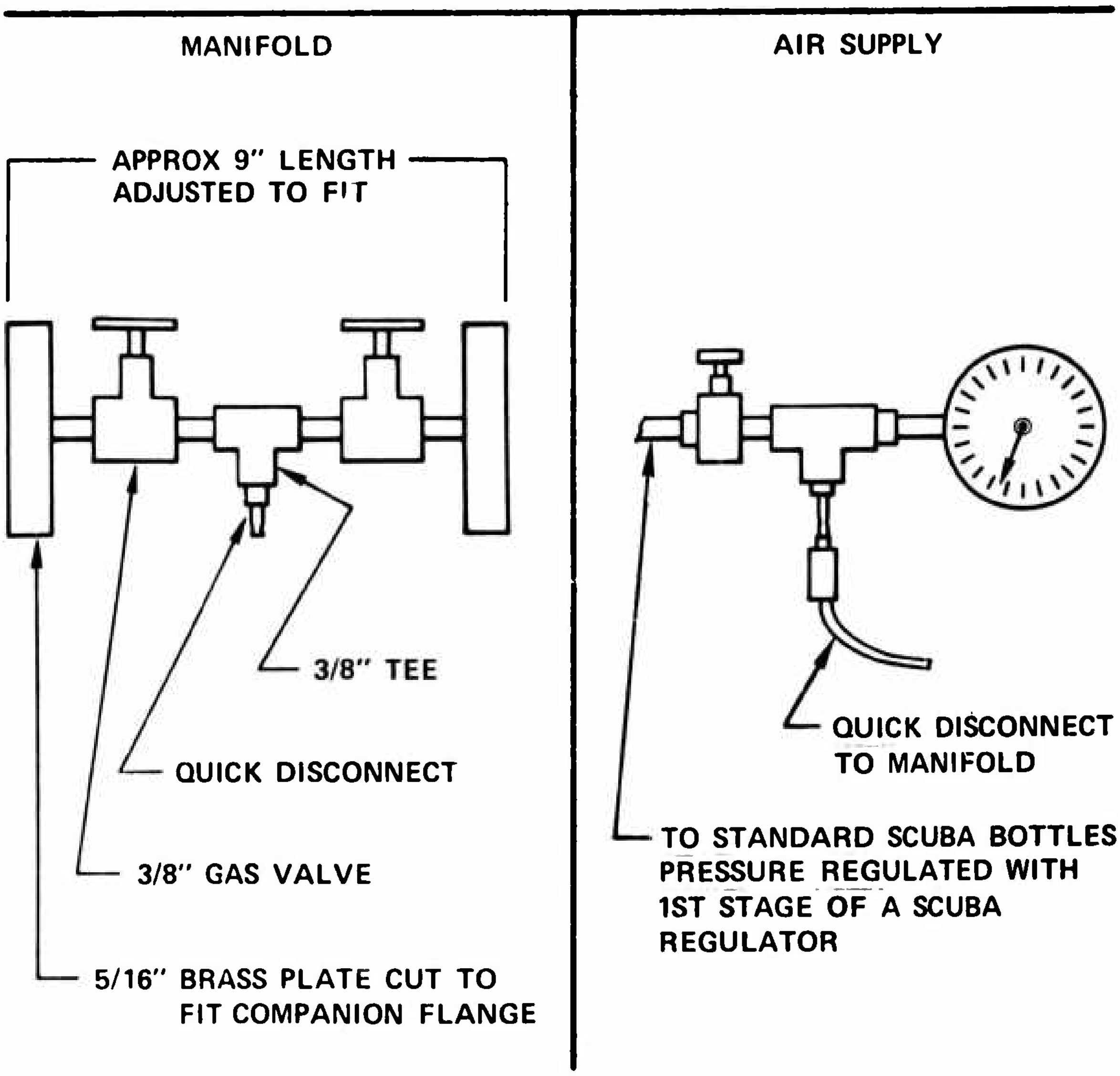
THE UCLA PIPE PUZZLE ASSEMBLY TASK

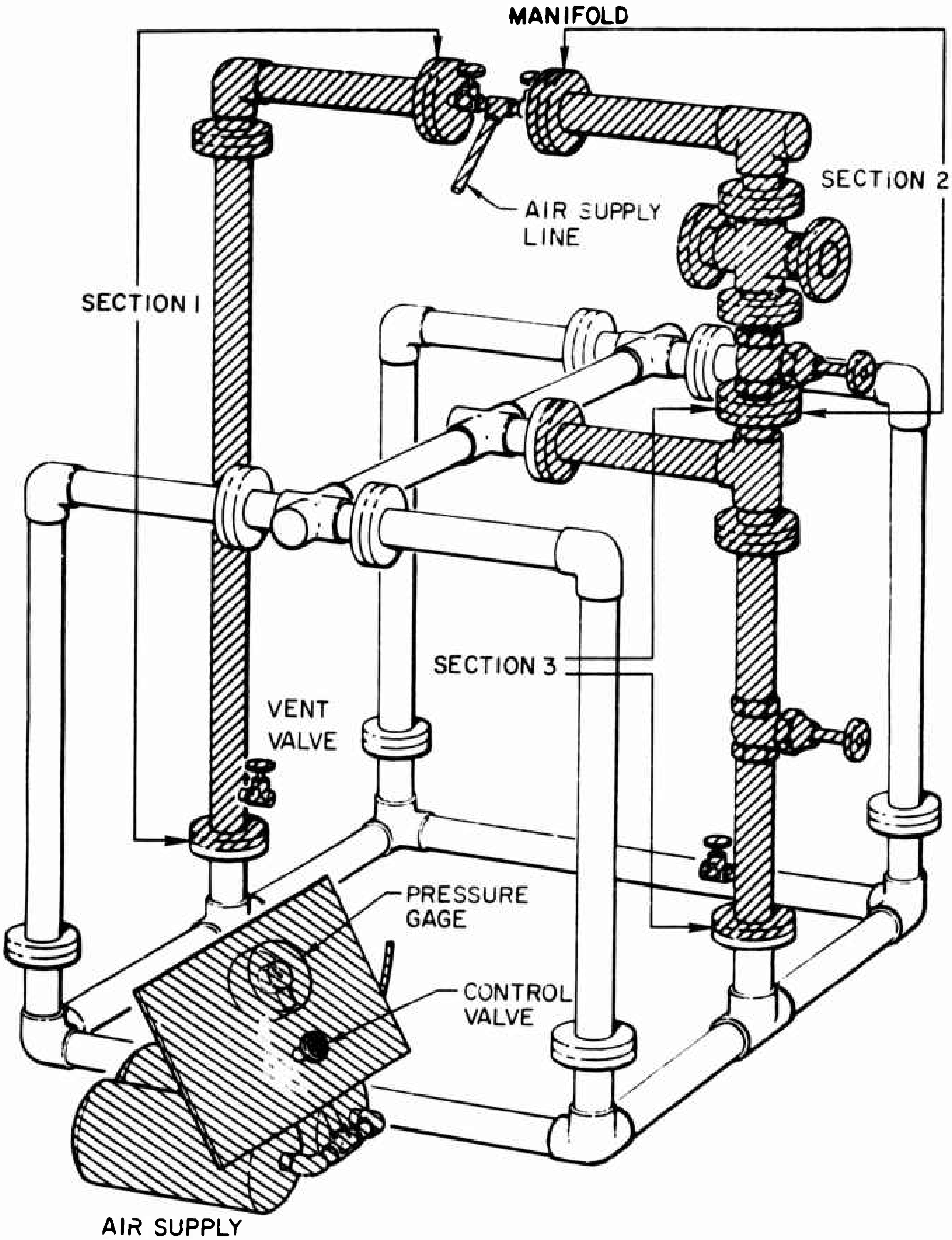
PIPE PUZZLE

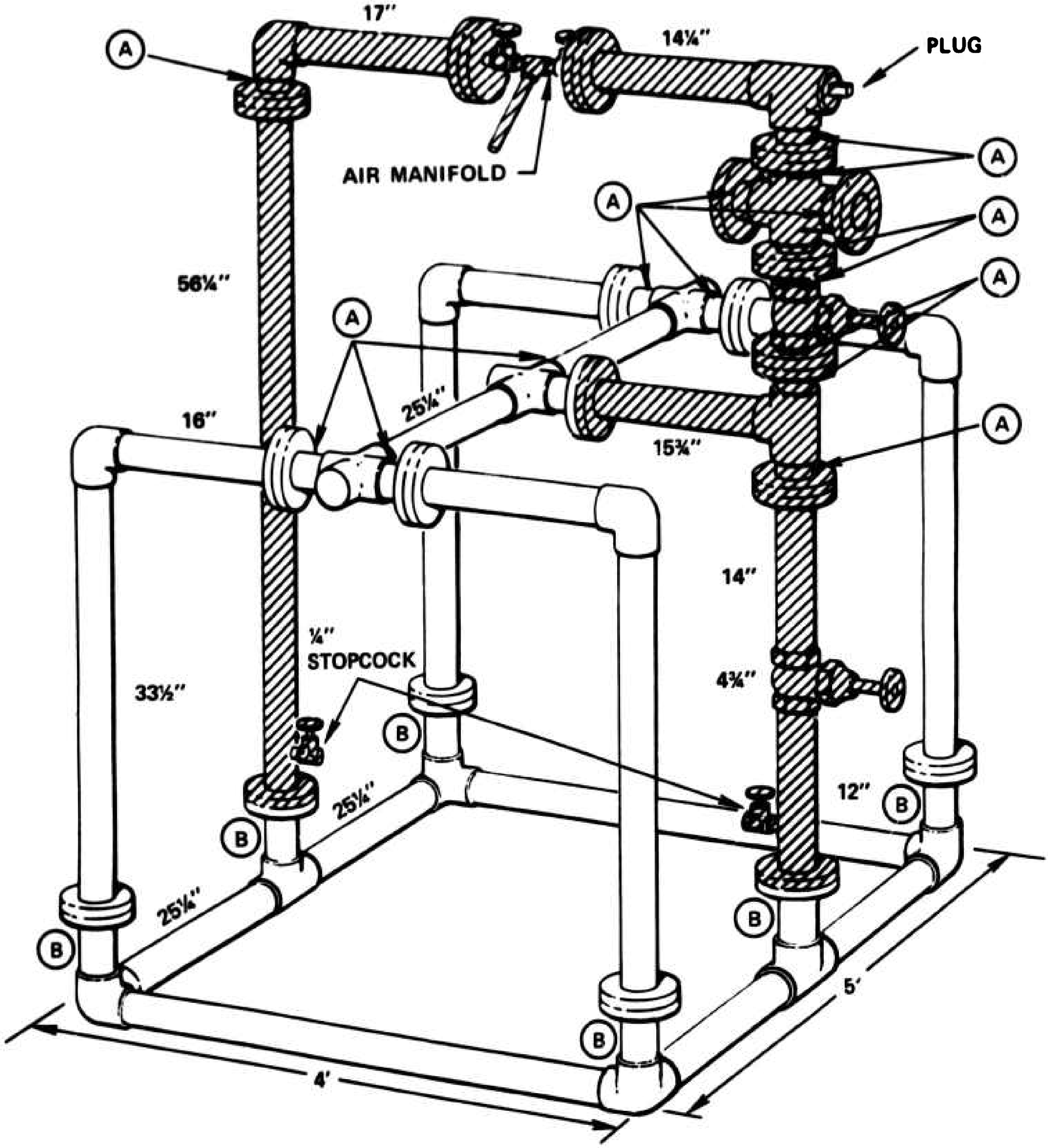
The pipe puzzle is contructed of two inch galvanized pipe and standard galvanized fittings. The pipe lengths shown on the drawing are the lengths that the pipe should be cut and threaded. A thread penetration of one half inch is allowed for.

The indicated spot welds are intended to prevent twisting during assembly and disassembly.

To complete the base, it is necessary to cut one of the base members without threads at one end and to weld this end to the last side outlet ell.

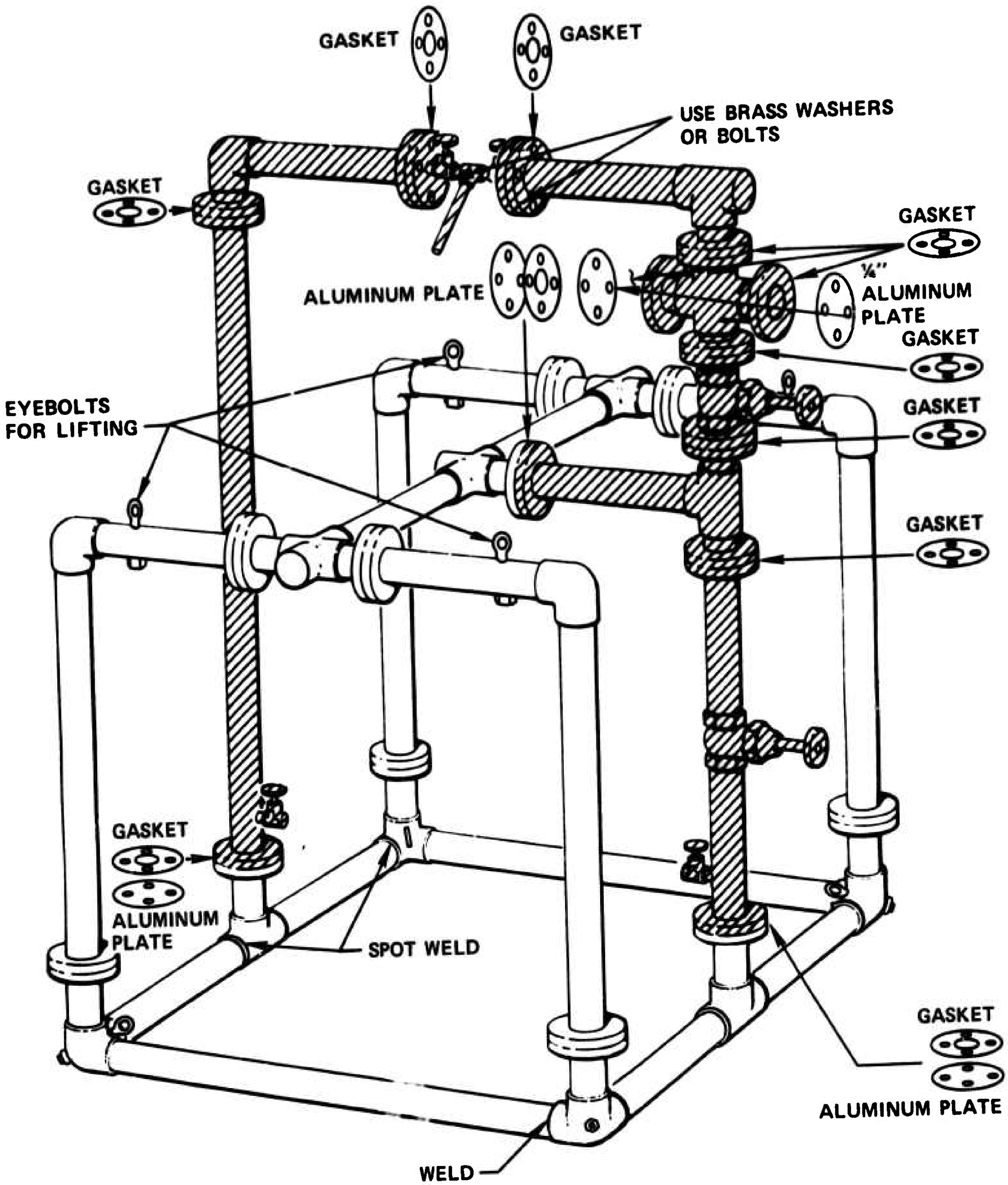



MANIFOLD
SECTION 2
AIR SUPPLY
LINE
SECTION I
SECTION 3
VENT
VALVE
PRESSURE
GAGE
CONTROL
VALVE
AIR SUPPLY



Ⓐ 2" X 2" CLOSE NIPPLE

Ⓑ 2" X 5" NIPPLE


GASKET
GASKET
USE BRASS WASHERS OR BOLTS
GASKET
GASKET
ALUMINUM PLATE
¼" ALUMINUM PLATE
GASKET
EYEBOLTS FOR LIFTING
GASKET
GASKET
GASKET
ALUMINUM PLATE
SPOT WELD
GASKET
ALUMINUM PLATE
WELD

MATERIAL LIST

Pipe Puzzle: Item	Quanitity
2" elbows	5
2" tees	3
2" crosses	4
2" side outlet ells	4
2" x 2" close nipples	15
2" x 5" nipples	6
6" dia., 4 hole, 2" pipe companion flange	36
2" plug	1
2" galvanized pipe	Approx. 48 feet
2" gate valves	2
1/4" stopcocks	2
3/8" x 6" eyebolts and nuts and washers	8
5/8" x 2" bolts and nuts	80
5/8" brass washers	8
1/8" aluminum backup-plates	7
1/8" solid rubber gaskets	5
1/8" holed rubber gaskets	7
1/4" aluminum plates	2

Manifold:

5/16" Brass plates Cut and drilled to fit companion flange	2
3/8" pipe, brass close nipples	2
3/8" brass pipe	Approx. 6"
3/8" gas valves	2

APPENDIX II

HEART RATE PROGRAM FLOW CHART

HEART RATE PROGRAM FLOW CHART