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PERSONAL FLOTATION DEVICES RESEARCH - PHASE II

VOLUME 1 - EXECUTIVE SUMMARY AND PROPOSED TECHNICAL APPROACH

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FEBRUARY 1978

FINAL REPORT

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16. Abstract

Research on the development of a comprehensive system for evaluating the life-saving capability of Personal Flotation Devices (PFDs) is reported. The approach contained herein evaluates PFDs on the basis of a probabilistic equation called the Life-Saving Index (LSI), which includes parameters measuring device assessiblity, wearability, ease of donning after an accident, effectiveness when held or worn, and reliability. A projected benefit of 48 lives per year is shown, through a minimum cost impact implementation of the Life-Saving Index System. This minimum cost impact approach consists of implementation of the LSI System through an optional "Type X" approval using the LSI System. Type X devices, which could include inflatable and hybrid PFDs, would be required to have a LSI higher than present Type III devices. PFDs would be submitted for LSI System approval only if the manufacturer chose to, and sold only if the public wanted to buy and utilize the more effective Type X device. Definitions and means of determining the value of each of the parameters of the LSI, for a given PFD, are given along with recommendations for future work and preliminary test procedures for future approval/certification programs.

Estimated costs and benefits, based on accident data, laboratory field testing, and field observations are given for the Type X implementation approach as well as alternative implementation plans.

Volume 2 is the technical report for this research program, and Volume 3 contains appendices to Volume 2.

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Unclassified	Unclassified	53	

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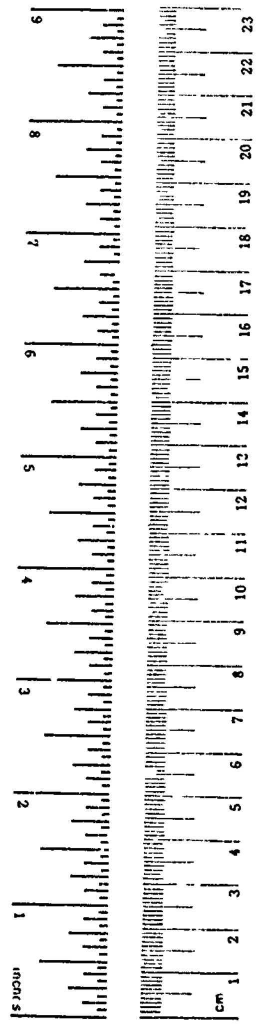
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

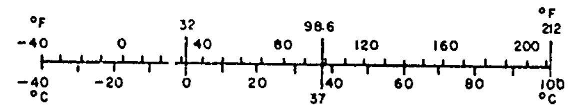
Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



VOLUME 1

EXECUTIVE SUMMARY AND

PROPOSED TECHNICAL APPROACH

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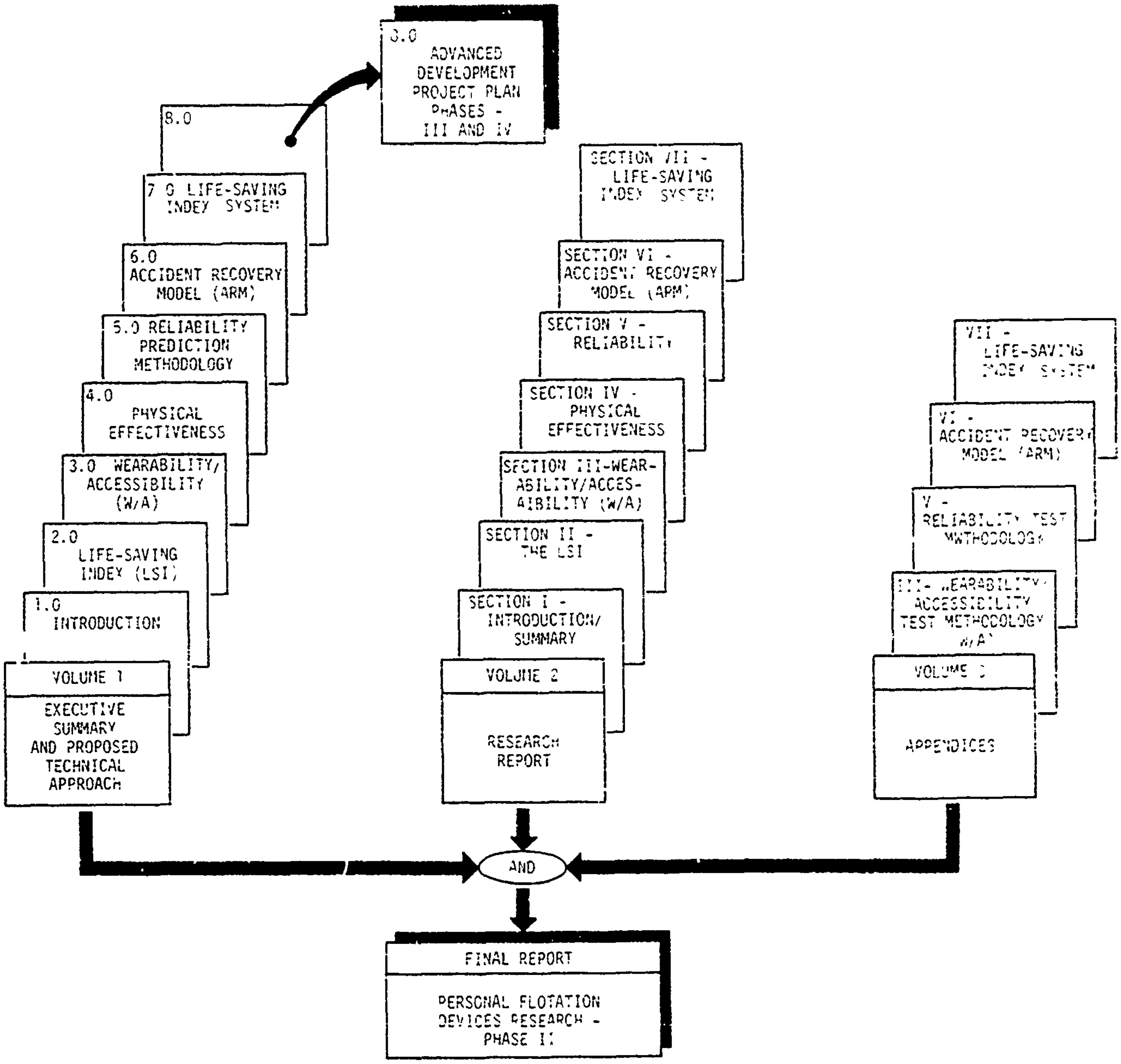

FIGURE 1. PICTORAL TABLE OF CONTENTS OF COMPLETE PHASE II REPORT

VOLUME 1 - EXECUTIVE SUMMARY AND PROPOSED TECHNICAL APPROACH

SECTION 1.0 INTRODUCTION AND BACKGROUND

This volume contains an executive summary and proposed technical approach for research on personal flotation devices (PFDs) conducted by Wyle Laboratories under contract to the U.S. Coast Guard. The objective of the Coast Guard's PFD research program is to develop a system for evaluating the overall life-saving capability of PFDs used in recreational boats.* The Phase I PFD research effort at Wyle began in July 1975. The Phase II effort, which culminates with this report, began in October 1976. The objectives of the Phase I and II efforts are listed below:

- Develop a single approach or possibly alternative approaches for the implementation of a PFD approval procedure which encompasses PFD physical effectiveness, reliability, and wearability/accessibility and is applicable to all types of presently approved devices (wearable and throwable) as well as inflatable and hybrid devices.

- Individual measures of physical effectiveness, reliability, and wearability/accessibility will be combined into a single lifesaving index (LSI), a quantitative measure of overall PFD effectiveness.

- The physical effectiveness of a PFD when worn (E_W), the physical effectiveness of a PFD when held (E_H), the probability that the accident victim dons the PFD in the water (P_D), will be established.

- Wearability/accessibility: the probability that the PFD is worn immediately prior to entering the water in an accident (I_W) and the probability that the PFD is accessible to a boater but not worn initially upon entering the water in an accident (I_{AC}) will be established. A wearability/accessibility test program will include inherently buoyant, inflatable, and hybrid test devices.

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*Whenever the term "boat" appears in the balance of this report, it means recreational watercraft subject to regulation through the Federal Boat Safety Act of 1971.

- Reliability : the probability that a PFD (both new and aged) performs as designed will be established. Results of accelerated aging tests, real-world aging tests, and a used device collection program will be correlated. The average failure rate over time will be modeled to develop a reliability index (or indices) for inherently buoyant, inflatable, and hybrid devices.

- Integrate the results of the above three subtasks into a single LSI. Develop estimates of the safety benefits to be realized and the costs and problems involved in the implementation of such an approval procedure. Potential approval procedure requirements (equipment, subjects, time) for the Coast Guard and for PFD manufacturers will be discussed. Recommendations for implementation of the LSI approval procedure and possible requirements for validation testing will be discussed.

- The data base of the Accident Recovery Model (ARM) will be expanded by the coding of 300 additional accidents. Those ARM factors of specific concern to this research task will then be analyzed.

Again, the overall objective of the Coast Guard's PFD research program is to develop a system for evaluating overall life-saving capability of PFDs used in recreational boats.

Sections 2.0 through 7.0 of this volume are summaries of major components of the present research. The section numbers in this volume correspond to those in Volume 2, which is a detailed technical presentation of each component of the PFD research effort conducted at Wyle. This volume (Section 8.0) also presents recommendations for future work, including resource requirements and schedules (see Figure 1). In order to put the present effort in context, a brief history of the Coast Guard's PFD research is presented below.

The PFD research program was initiated in 1968 and has included many projects conducted by both the Coast Guard and contractors. The first contract was awarded to Booz-Allen Applied Research to investigate the physical effectiveness of PFDs. That project was redirected, and Arthur D. Little received a contract to conduct tests to determine the quantity of flotation and righting moment necessary to float different percentile levels of the U.S. adult population and to develop a human buoyancy and stability model. During this time, the initial concept of the Life-Saving Index was developed. The Life-Saving Index, which will be presented in more detail, basically is concerned with the concept that the life-saving capability of a specific PFD design can be measured through some combination of four parameters:

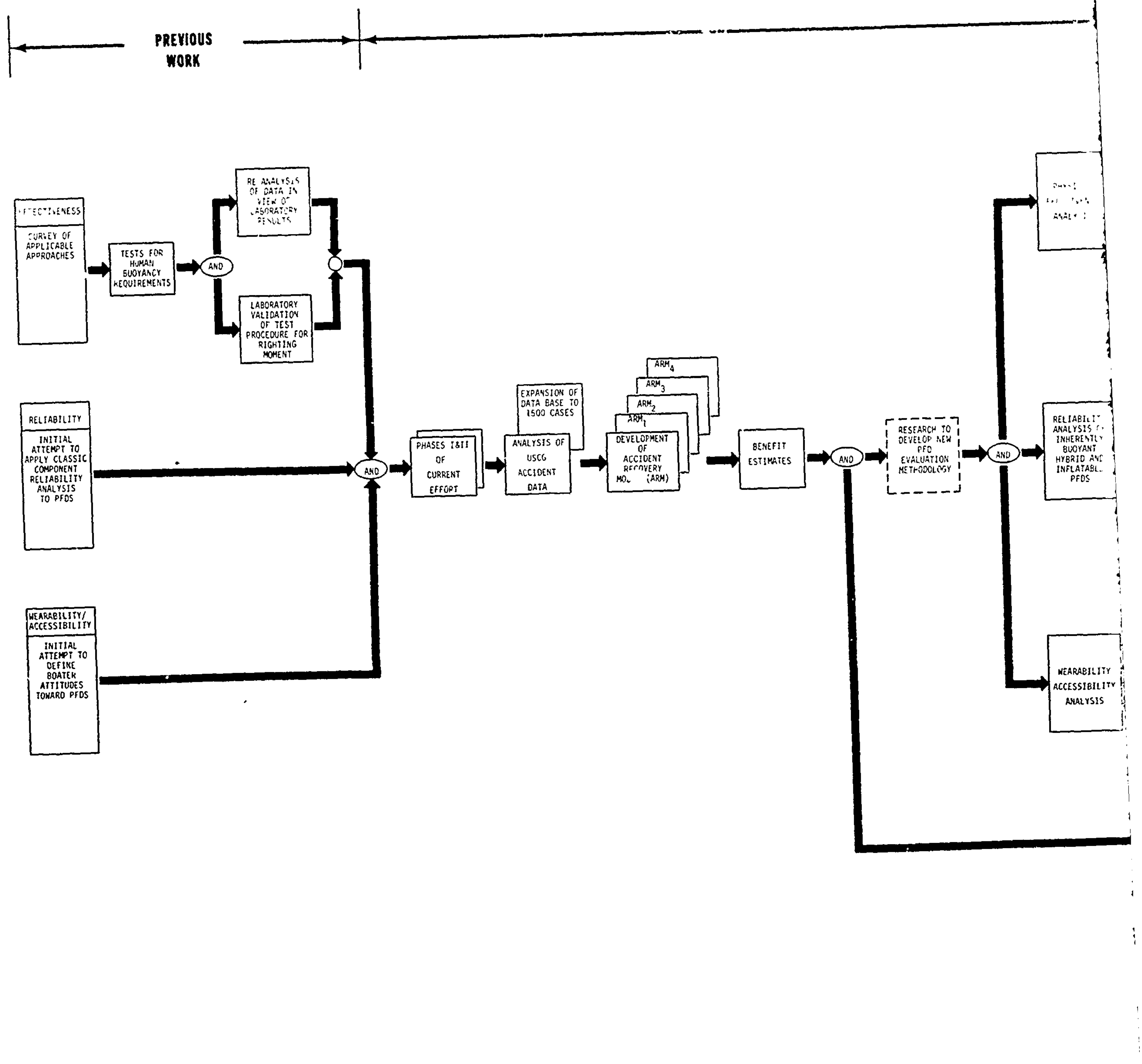
- Wearability - The probability that the device is worn
- Accessibility - The probability that it is accessible if not worn
- Physical Effectiveness - The capability of the PFD to float the victim sufficiently so that he will live, given that he is wearing or holding it
- Reliability - The probability that the device functions to a minimum level of performance for a specified service life.

The left-hand portion of Figure 2 shows the work accomplished on each of these parameters prior to the present effort. The remainder of Figure 2 outlines PFD research conducted by Wyle.

As can be seen from the figure, initial work on effectiveness was followed by two efforts aimed at independently developing a PFD test procedure to apply the human buoyancy and stability model using actual PFDs. The stability model approach was found to be too sensitive to be practically applied to a reproducible PFD evaluation procedure. Work on a practical effectiveness test procedure continued as part of this effort and is reported in Section IV of Volume 2.

Preliminary work on wearability took the form of a "threshold" model. The model did not produce satisfactory predictions and was supplanted by a statistical approach based on boater evaluations of PFDs in the field. Initial work on reliability took the form of a model which expressed the reliability of the whole PFD as a function of the reliability of elementary components. The approach to reliability was simplified in the present work and emphasizes practical methods for evaluating the reliability of a PFD in the recreational boating environment (such as accelerated aging). Work on the wearability/accessibility and reliability indices composed a major part of the effort described in this report. Section III (Volume 2) covers Wearability/Accessibility and Section V (Volume 2) covers Reliability.

The purpose of this volume is to provide management personnel with an overview of work performed and to present a proposed approach for advanced development of the PFD program.



PREVIOUS WORK
EFFECTIVENESS
SURVEY OF APPLICABLE APPROACHES
TESTS FOR HUMAN BUOYANCY REQUIREMENTS
AND
LABORATORY VALIDATION OF TEST PROCEDURE FOR RIGHTING MOMENT
RELIABILITY
INITIAL ATTEMPT TO APPLY CLASSIC COMPONENT RELIABILITY ANALYSIS TO PFDS
WEARABILITY/ ACCESSIBILITY
INITIAL ATTEMPT TO DEFINE BOATER ATTITUDES TOWARD PFDS
AND
PHASES I&II OF CURRENT EFFORT
EXPANSION OF DATA BASE TO 1500 CASES
ANALYSIS OF USCG ACCIDENT DATA
ARM4
ARM3
ARM2
ARM1
DEVELOPMENT OF ACCIDENT RECOVERY MODEL (ARM)
BENEFIT ESTIMATES
AND
RESEARCH TO DEVELOP NEW PFD EVALUATION METHODOLOGY
AND
WEARABILITY ACCESSIBILITY ANALYSIS

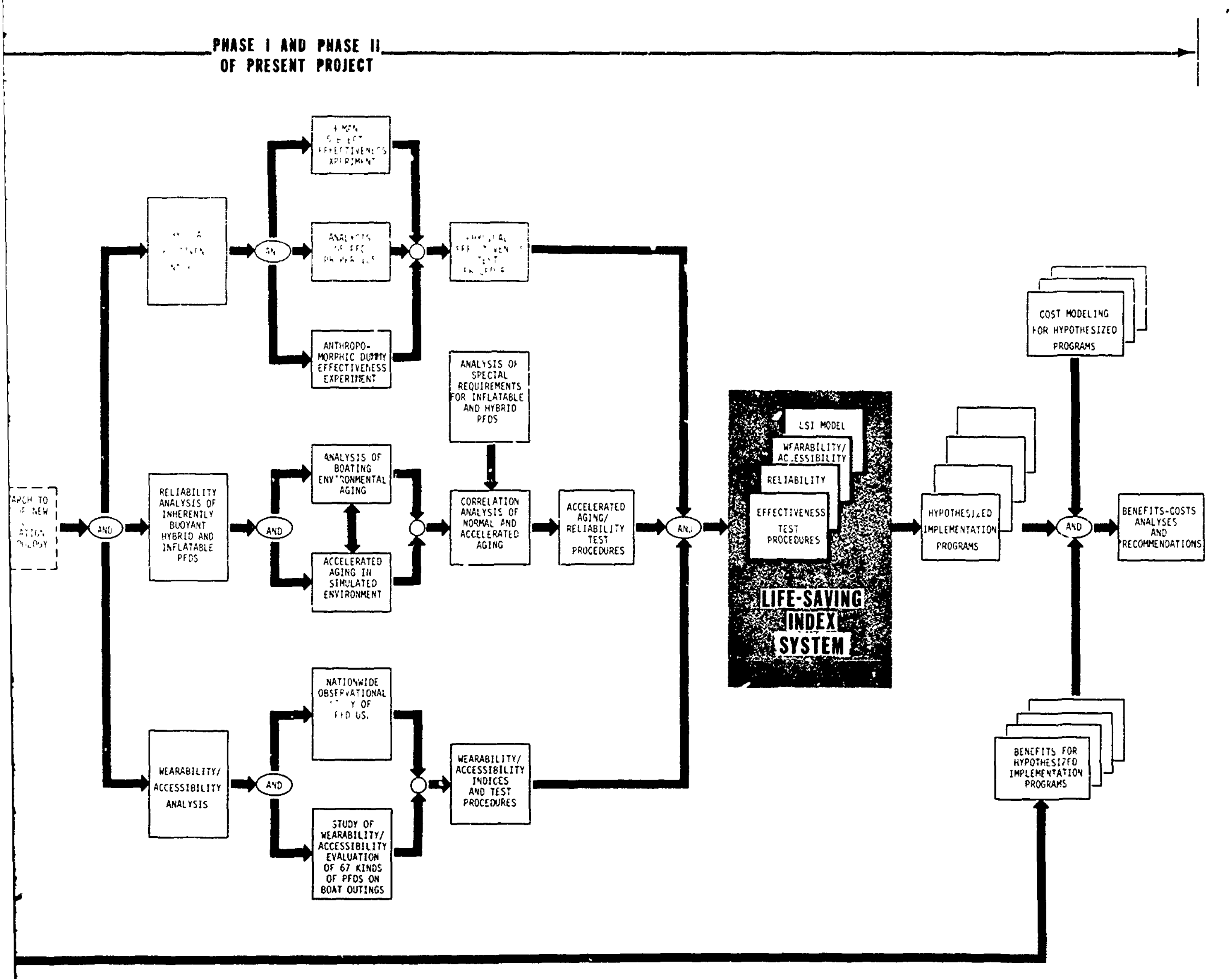


FIGURE 2. SYNOPSIS OF SIGNIFICANT PFD RESEARCH

SECTION 2.0
THE LIFE-SAVING INDEX (LSI)

The purpose of the PFD research program was to develop a method for evaluating the overall life-saving capability of PFDs. The proposed method is called the Life-Saving Index System. The LSI System is composed of: a) test methods for evaluating PFD wearability, accessibility, effectiveness and reliability, b) indices of PFD wearability, accessibility, effectiveness, and reliability, and c) the LSI which is a formula numerically combining the latter indices into an overall index of life-saving capability. The components of the LSI System are pictorialized in Figure 3. The LSI System is applicable to diverse types of PFDs, including inflatables and hybrids as well as inherently buoyant devices. The LSI System gains its wide applicability from the fact that it is performance-oriented. The LSI System predicts the life-saving performance of the PFD in the recreational boating environment. Some of the advantages of the LSI System relative to the current PFD approval process include:

- The LSI System will help to foster the development of innovative PFD designs by industry and will provide the Coast Guard with a method for evaluating the life-saving capability of these designs.

- The LSI System permits the evaluation of trade-offs between reliability, wearability, accessibility, and effectiveness.

- The LSI System makes it possible to compare diverse PFDs on a common continuum of life-saving potential.

The LSI is a number between zero and one which represents the life-saving capability of a particular PFD design. A PFD having an LSI of 1 should prevent nearly all drownings from occurring; a PFD with an LSI of zero would be useless (and not a PFD). The LSI formula relates the following parameters:

I_W = The probability that the PFD is worn immediately prior to entering the water in an accident (the wearability index).

I_{AC} = The probability that the PFD is accessible to a boater but not worn initially upon entering the water in an accident (accessibility index).

P_D = The probability that the accident victim dons the PFD in the water.

P_H = The probability that the accident victim holds or lies upon the PFD in the water.

E_W = The probability that the PFD maintains or turns the wearer in the water to a position with a minimum required freeboard to the lower respiratory passage within a specified time limit (effectiveness when worn).

E_H = The probability that the PFD provides minimum required freeboard to the lower respiratory passage for a relaxed person holding or lying upon the device in the water (effectiveness when held).

R = The probability that a PFD will operate successfully for a specified period of time and under specified conditions when used in the manner and for the purpose intended (reliability).

The exact formula, which is based on probability theory is:

$$LSI = [I_W \cdot E_W + I_{AC} \cdot P_D \cdot E_W + I_{AC} \cdot P_H \cdot E_H] \cdot R$$

The formula above evolved, due to the efforts of the present research, from the initial concept:

$$LSI = I_E \times I_R \times I_W$$

where:

I_E = Physical effectiveness; the probability that the PFD maintains the wearer in a position which permits continuous breathing.

I_R = Reliability; the probability that the PFD performs as designed.

I_W = Wearability; the probability that the PFD is worn by the victim when he enters the water in a marine accident.

In the proposed Life-Saving Index System, the LSI serves as the primary tool for evaluating PFDs which are candidates for certification or approval (see Figure 3). The performance parameters of the PFD (wearability, accessibility, effectiveness, and reliability) would be measured as detailed in Sections III through V of Volume 2 of this report. The LSI can then be computed and compared to a minimum LSI established by the Coast Guard. Only those candidate PFDs which meet or exceed the minimum LSI would be certified or approved. In addition to establishing a minimum LSI, the Coast Guard may deem it desirable to establish minimums for the indices of effectiveness and reliability.

THE LIFE-SAVING INDEX SYSTEM

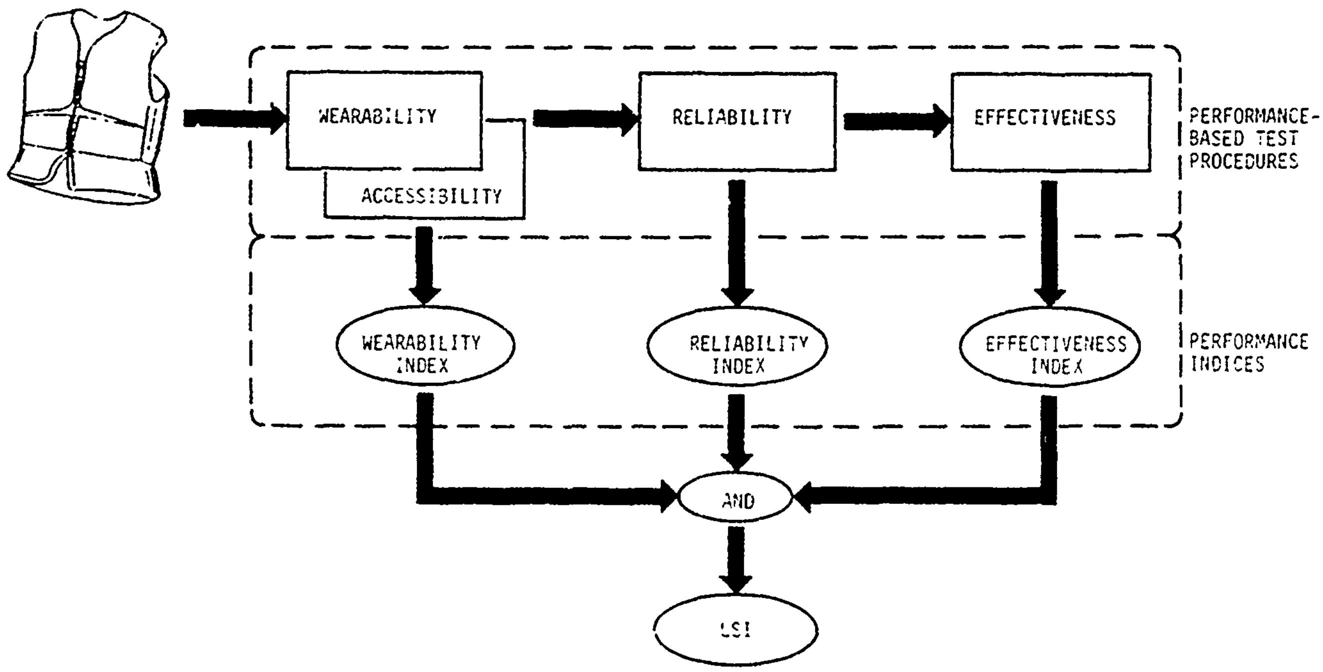


FIGURE 3. OVERVIEW OF THE LIFE-SAVING INDEX SYSTEM FOR EVALUATING PFDS

SECTION 3.0

DEVELOPMENT OF WEARABILITY/ACCESSIBILITY INDICES

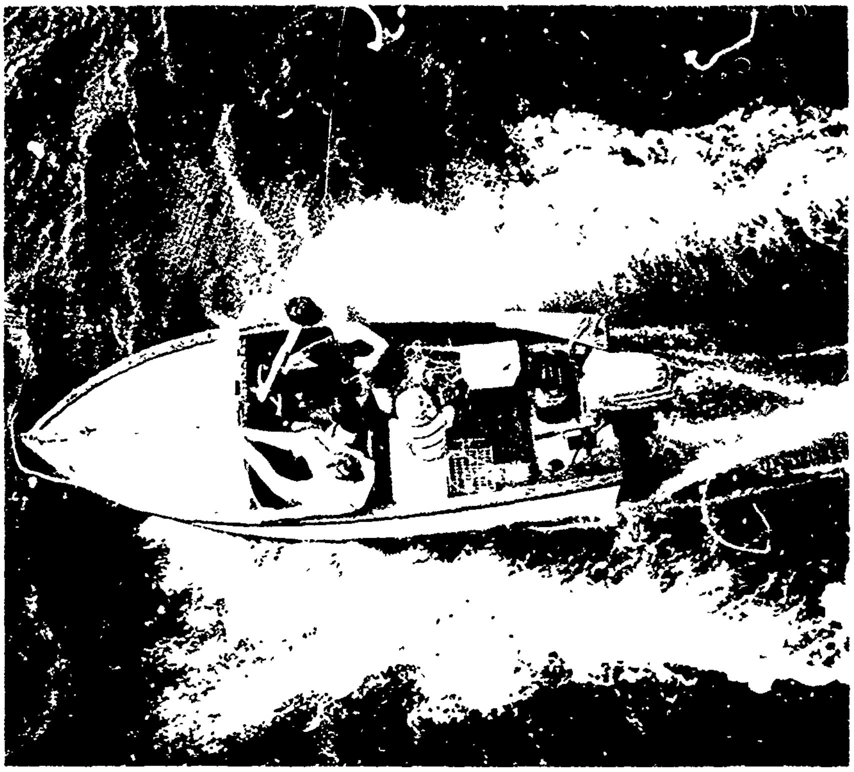
The life-saving capability of PFDs depends critically upon wearability. The wearability of a PFD is defined as the probability that the PFD is worn by the victim when he enters the water in a boating accident. At the inception of this project, PFD effectiveness and reliability were believed to be reasonably high for Coast Guard approved devices. However, reports from a variety of sources suggested that the wearability of PFDs is low.

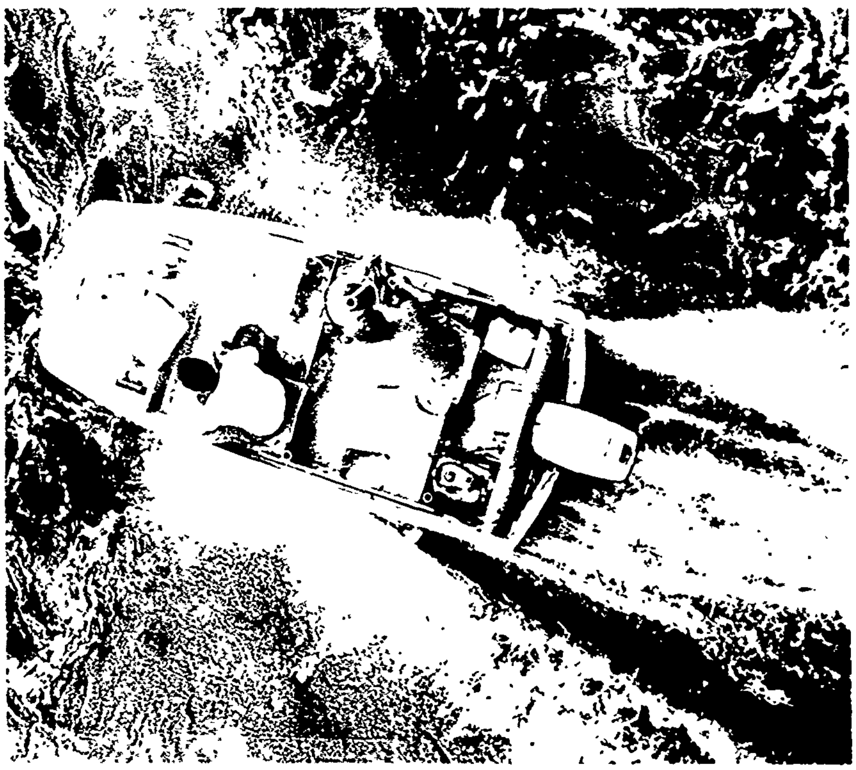
Accessibility of a particular model PFD is defined as the probability that the PFD will be accessible to the boater, but not worn initially upon entering the water in a recreational boating accident, given that the PFD was on board.

A two-fold approach to the wearability/accessibility problem has been pursued in the present project (see Figure 4). Section III of Volume 2 describes an observational study of PFD accessibility and wear. The goal of this study was to obtain accurate estimates of PFD wearability and accessibility in recreational boating through the United States. The observational study identifies significant conditions in the boating environment which affect PFD use and provides valuable base-line data and parameters for the development of PFD evaluation procedures. The present wear rate appears to be about 7%.

A second set of field studies was undertaken to develop a method for predicting the wearability and accessibility of PFDs in recreational boating. A panel of 36 boaters evaluated PFDs as part of their boating activity. Each participant received between three and six different types of PFDs to evaluate, and extensive data on his attitudes and use of each device were obtained. The studies were directed at: 1) developing test procedures for evaluating the wearability and accessibility of candidate PFDs, and 2) based on these test procedures, developing indices of wearability and accessibility which serve as inputs to the Life-Saving Index (LSI). These field studies examine the effect of PFD properties, boater characteristics and attitudes, and situational/environmental factors on PFD wearability and accessibility, based on the amount of time boaters actually wore and used test PFDs and boaters' evaluations on structured rating scales. It is demonstrated that these indices are both valid and reliable. The predicted wearabilities of PFDs measured in the field tests matched closely the results obtained in the observational study. An accuracy of prediction of ±0.05 for both the wearability and accessibility indices can be achieved using as few as 12 boaters to evaluate PFDs on two outings each.

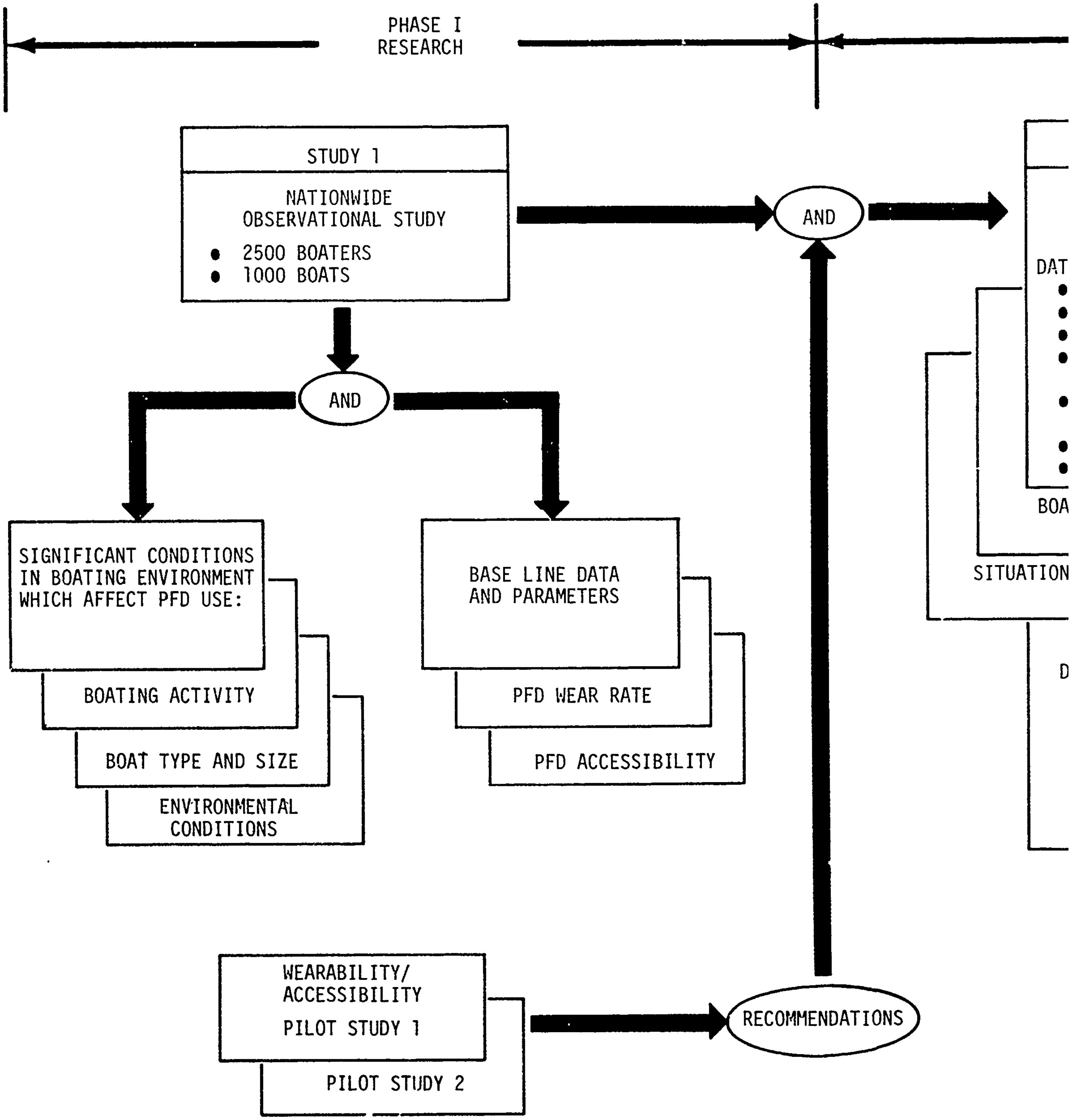
A preliminary evaluation plan for use in an approval/certification procedure is in Section III of Volume 2.





EXAMPLE PHOTOGRAPHS FROM THE NATIONWIDE
OBSERVATIONAL STUDY OF PFD WEAR AND ACCESSIBILITY

4 224.1.


PHASE I
RESEARCH
STUDY 1
NATIONWIDE
OBSERVATIONAL STUDY
2500 BOATERS
1000 BOATS
AND
AND
SIGNIFICANT CONDITIONS
IN BOATING ENVIRONMENT
WHICH AFFECT PFD USE:
BOATING ACTIVITY
BOAT TYPE AND SIZE
ENVIRONMENTAL
CONDITIONS
BASE LINE DATA
AND PARAMETERS
PFD WEAR RATE
PFD ACCESSIBILITY
WEARABILITY/
ACCESSIBILITY
PILOT STUDY 1
PILOT STUDY 2
RECOMMENDATIONS
DAT
BOA
SITUATION
D

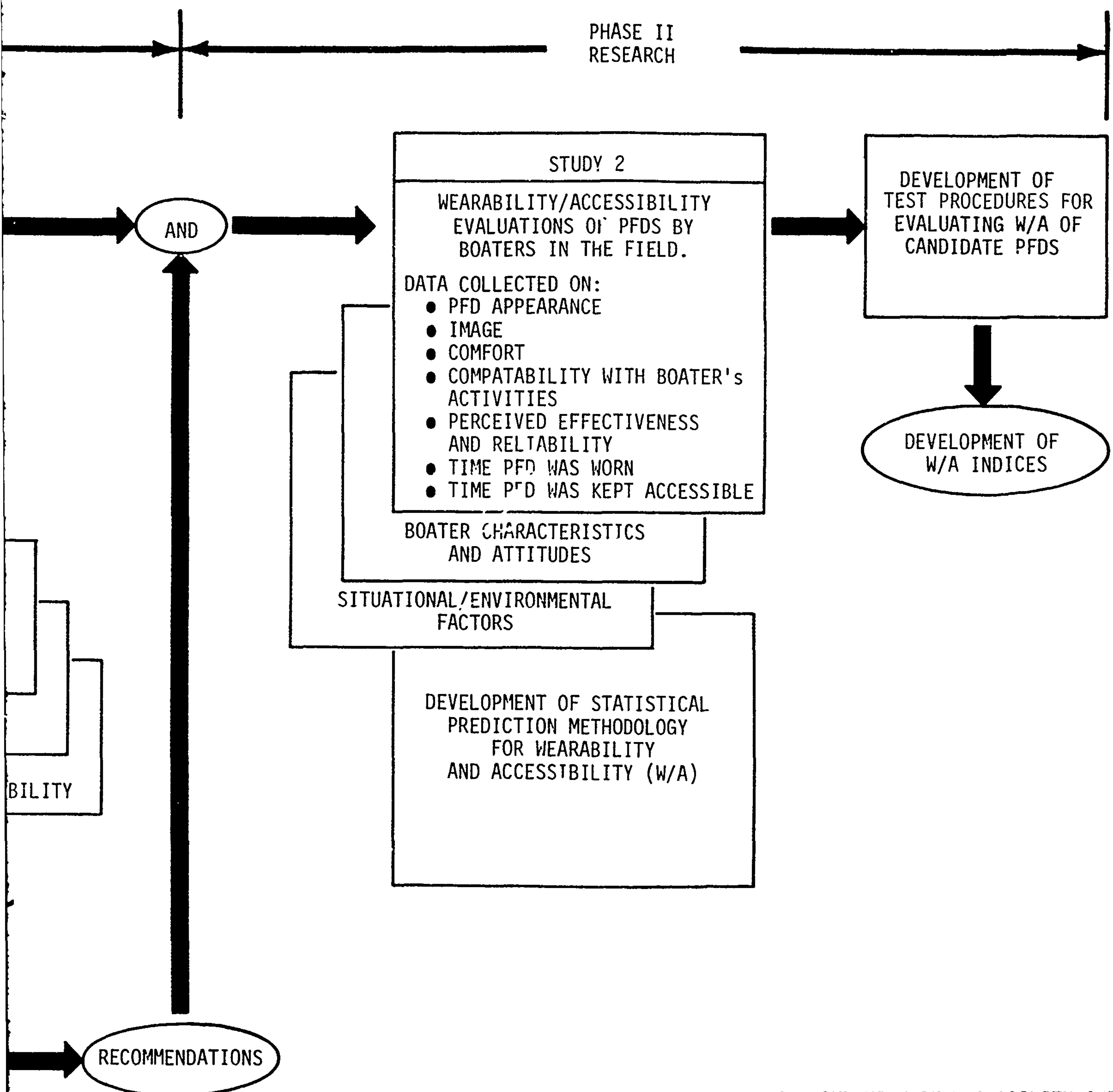


FIGURE 4. OVERVIEW OF WEARABILITY AND ACCESSIBILITY RESEARCH

4 224.1.

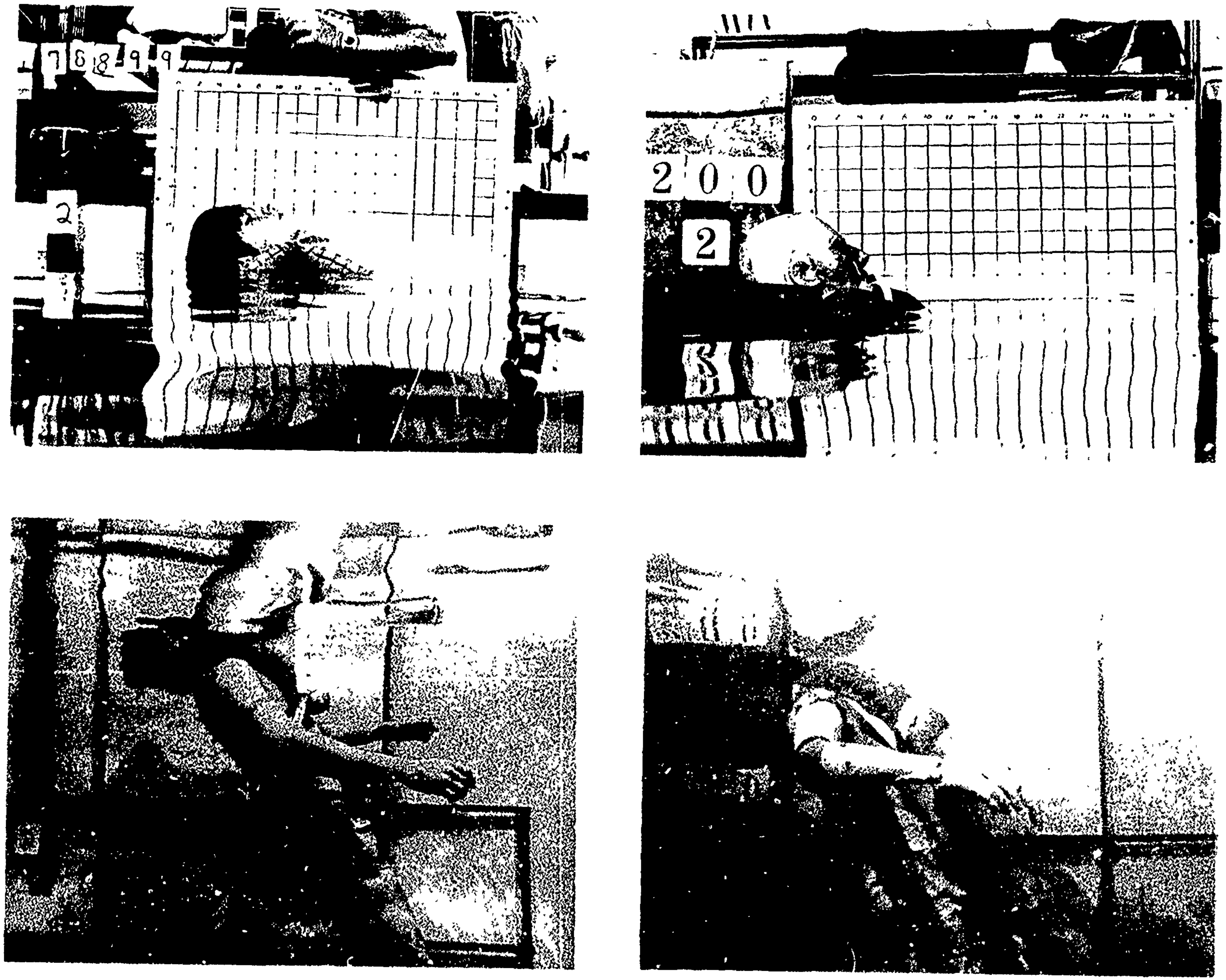
SECTION 4.0
PHYSICAL EFFECTIVENESS

The physical effectiveness of a PFD is defined as the probability that the device keeps the wearer floating in a position which permits continuous breathing, and is the principal basis for approval under the current Coast Guard approval procedures. In order to permit continuous breathing, the device must: (a) have sufficient buoyancy, and (b) maintain the individual in a vertical or slightly backward-leaning orientation. The principal measure of orientation is the equilibrium angle, defined as the angle between vertical and the centerline of the wearer's body.

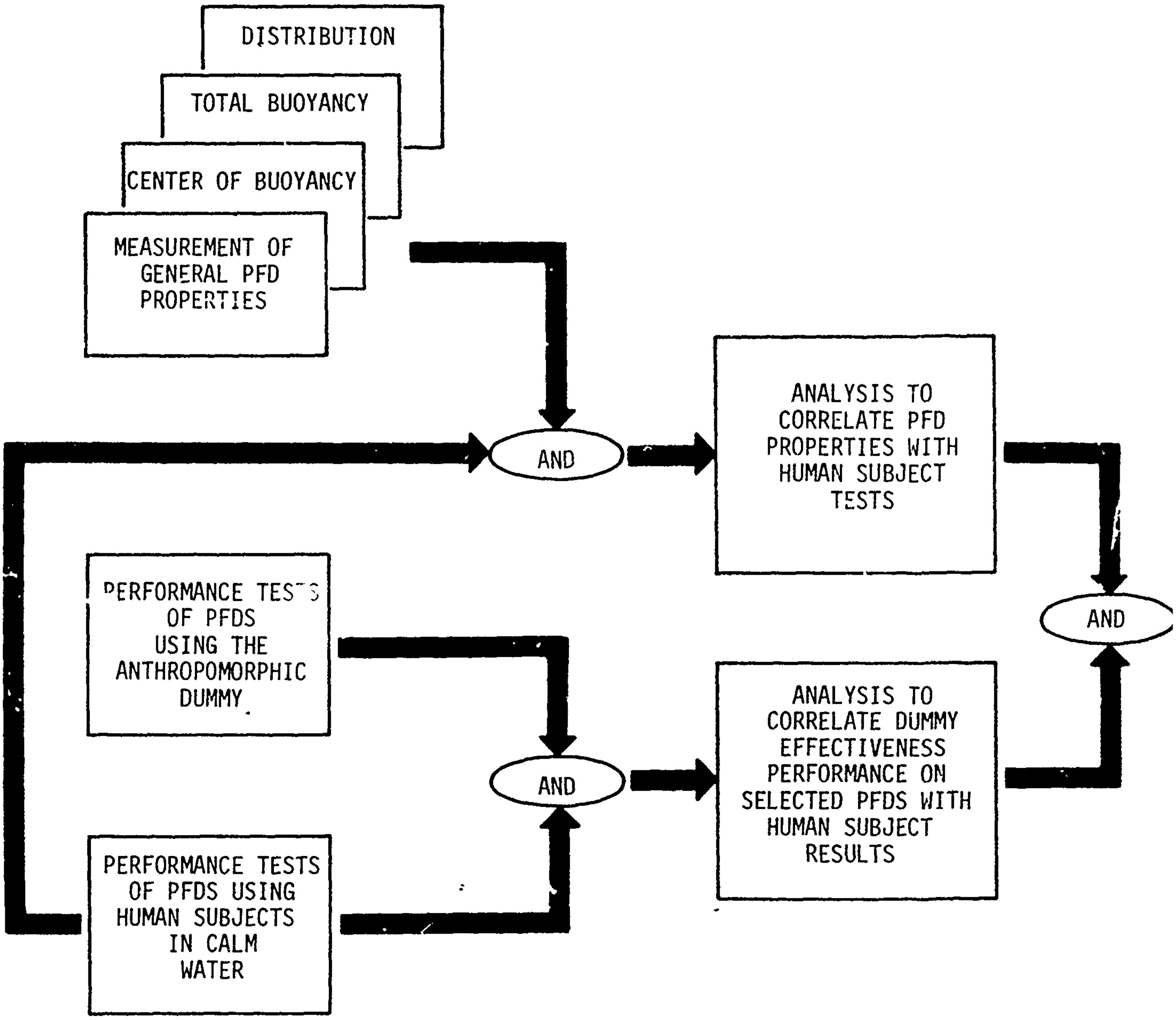
Wyle's initial approach to the PFD effectiveness problem was to refine the human body buoyancy model formulated by Arthur D. Little, Inc. In any modeling effort, it is necessary to make certain assumptions in order to make the program manageable. As Wyle began work on refining the human body buoyancy model, it soon became clear that a host of complicating factors would have to be taken into consideration before the model could generate useful predictions. At the same time it became obvious that the effectiveness problem is more general than that of supporting an unconscious wearer in the water. The low rate of wear of PFDs suggests the need for methods of evaluating the effectiveness of a PFD when held or donned in the water, as well as when worn. These considerations led to the formulation of a revised approach to PFD effectiveness.

The revised approach investigated two alternative avenues to development of a method for evaluating PFD effectiveness. One of these is a set of general design criteria for PFDs. These criteria would include both buoyancy and buoyancy distribution considerations. Unfortunately, we found that satisfaction of the theoretical design requirements correlated poorly with actual PFD performance. The other is a test method which uses a human simulator or test dummy. A key characteristic of both of these methods is that they are primarily empirical. The development of the method and the process of evaluating PFDs for approval or certification is based entirely upon laboratory test results. The methods involve no assumptions about the buoyancy characteristics of the human body. Volume 2 details the results of an evaluation of these two approaches to determining PFD effectiveness, and strongly recommends that further development of the effectiveness evaluation approach using anthropometric dummies be pursued.

Using dummies, the physical effectiveness can be evaluated by determining the percentile level of the boating population (as represented by the dummies) which the PFD supports with a required amount of "freeboard" between the still water surface and the lower respiratory passage. Similarly, the percentile level of the population which the PFD turns upright from a face-down position can be determined. These same determinations may be made utilizing human subjects, but some reduction in reproducibility results. The dummy, used in our tests, had good correlation with the portion of the population that it was built to represent. An overview of the effectiveness program is shown in Figure 5.



EXAMPLE PHOTOGRAPHS OF THE HUMAN-SUBJECT
AND DUMMY PFD EFFECTIVENESS EXPERIMENT


DISTRIBUTION
TOTAL BUOYANCY
CENTER OF BUOYANCY
MEASUREMENT OF GENERAL PFD PROPERTIES
AND
ANALYSIS TO CORRELATE PFD PROPERTIES WITH HUMAN SUBJECT TESTS
PERFORMANCE TESTS OF PFDS USING THE ANTHROPOMORPHIC DUMMY
AND
AND
ANALYSIS TO CORRELATE DUMMY EFFECTIVENESS PERFORMANCE ON SELECTED PFDS WITH HUMAN SUBJECT RESULTS
PERFORMANCE TESTS OF PFDS USING HUMAN SUBJECTS IN CALM WATER

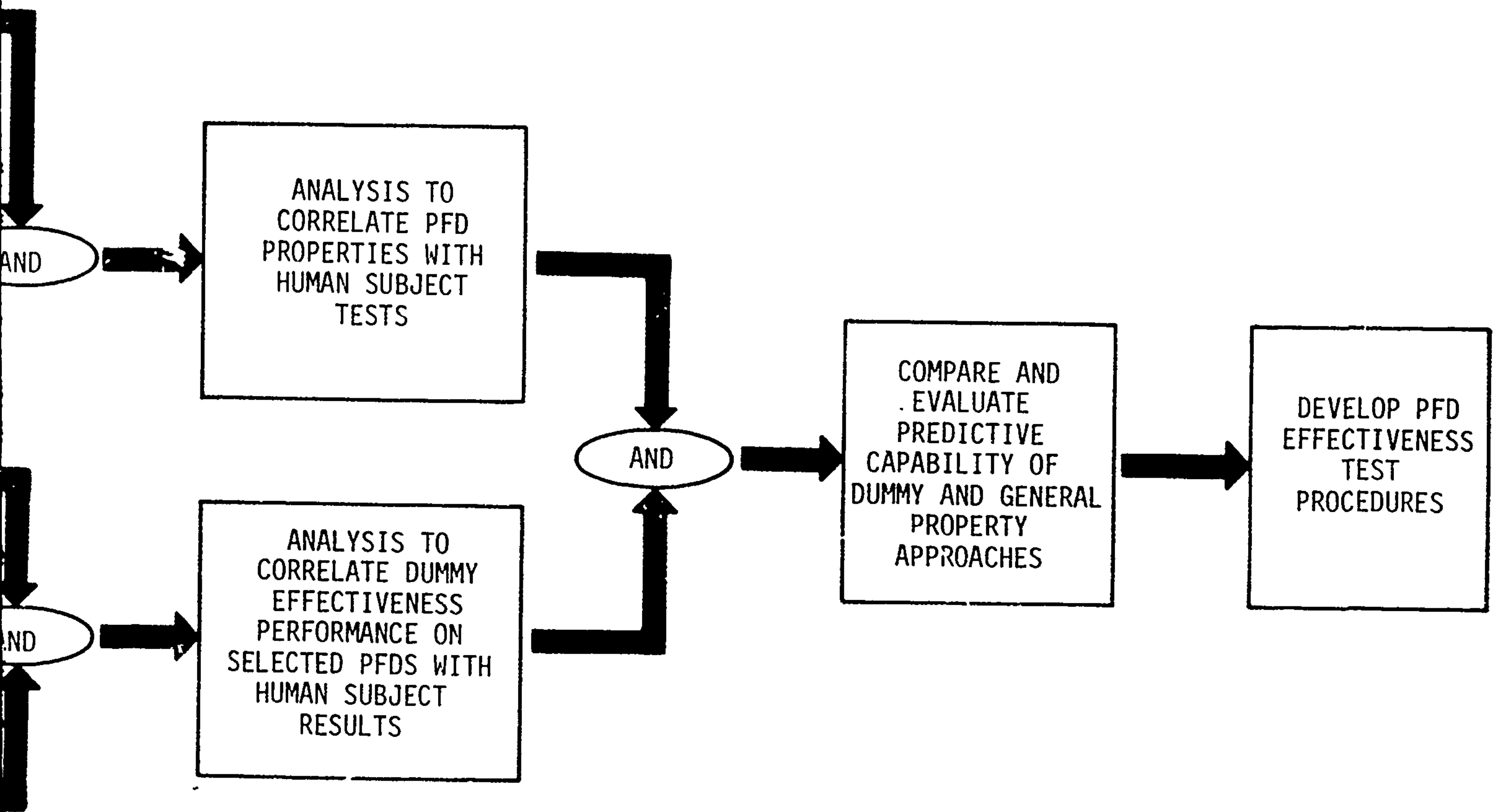


FIGURE 5. OVERVIEW OF PHYSICAL EFFECTIVENESS RESEARCH

SECTION 5.0
RELIABILITY PREDICTION METHODOLOGY

Reliability is defined as the probability that a PFD will perform its function of providing adequate buoyancy without failure under given recreational boating conditions for a given period of time. Reliability, therefore, is concerned with the functioning of the PFD for its entire useful life in the environment for which it was intended.

Reliability is included in the LSI model because it was theorized that new PFD designs could be more wearable if they were more compact. Such a PFD could get its buoyancy from an inflatable chamber(s) which in turn would increase wear rate, and save many lives. It was argued, however, that these new inflatable PFDs may be less reliable than existing USCG approved PFD designs whose buoyancy is a result of being manufactured with components which are naturally buoyant.

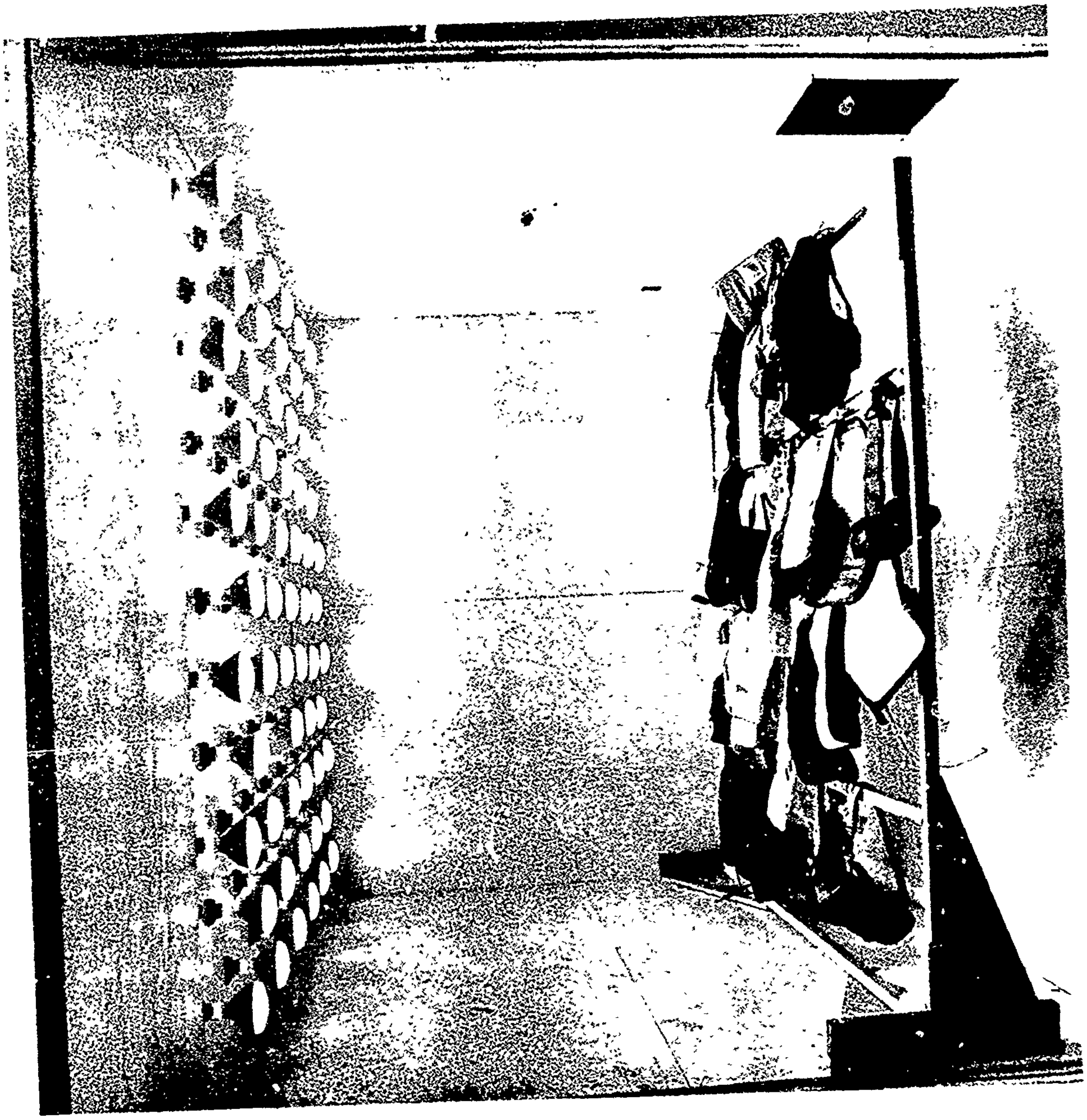
Therefore, a methodology had to be developed which could evaluate reliability of a PFD over a period of time, when subjected to an environment indicative of recreational boating. A pictogram (Figure 6) presents our approach. First, a sample of PFDs of a given model would be submitted to an accelerated aging process designed to simulate a number of years (that number to be determined by the Coast Guard) in the recreational boating environment. After the aging, the device would be activated (if an inflatable) and tested for buoyancy, and the average percent population which the model would support after aging computed. That percentage equals the reliability of the PFD.

The first part of Section V of Volume 2 addresses the development of a test sequence which simulates the recreational boating environment. This was done using currently approved inherently buoyant PFDs. PFDs which were used by recreational boaters were compared objectively to new PFDs which were subjected to a simulated recreational boating environment. The second part of this section is the reliability analysis of inflatable and hybrid PFDs. The analysis of these styles required that the simulated environment determined for certain inherently buoyant PFDs be supplemented with environmental factors which are uniquely detrimental to the reliability of inflatable PFDs.

A reliability Test Plan was developed which tested the susceptibility of inflatables to extremes of the recreational boating environment. The results from inflatable PFDs subjected to this test plan showed that an Accelerated Testing Technique is feasible for testing inflatable PFDs, that latent failure modes, which were either manufacturing or design problems, were transformed into detectable failures by the environmental stresses, and the state-of-the-art for selection types of inflatables is such that these types of inflatables are highly reliable. Additional work on maintainability and reliability is recommended in Section 8.0.

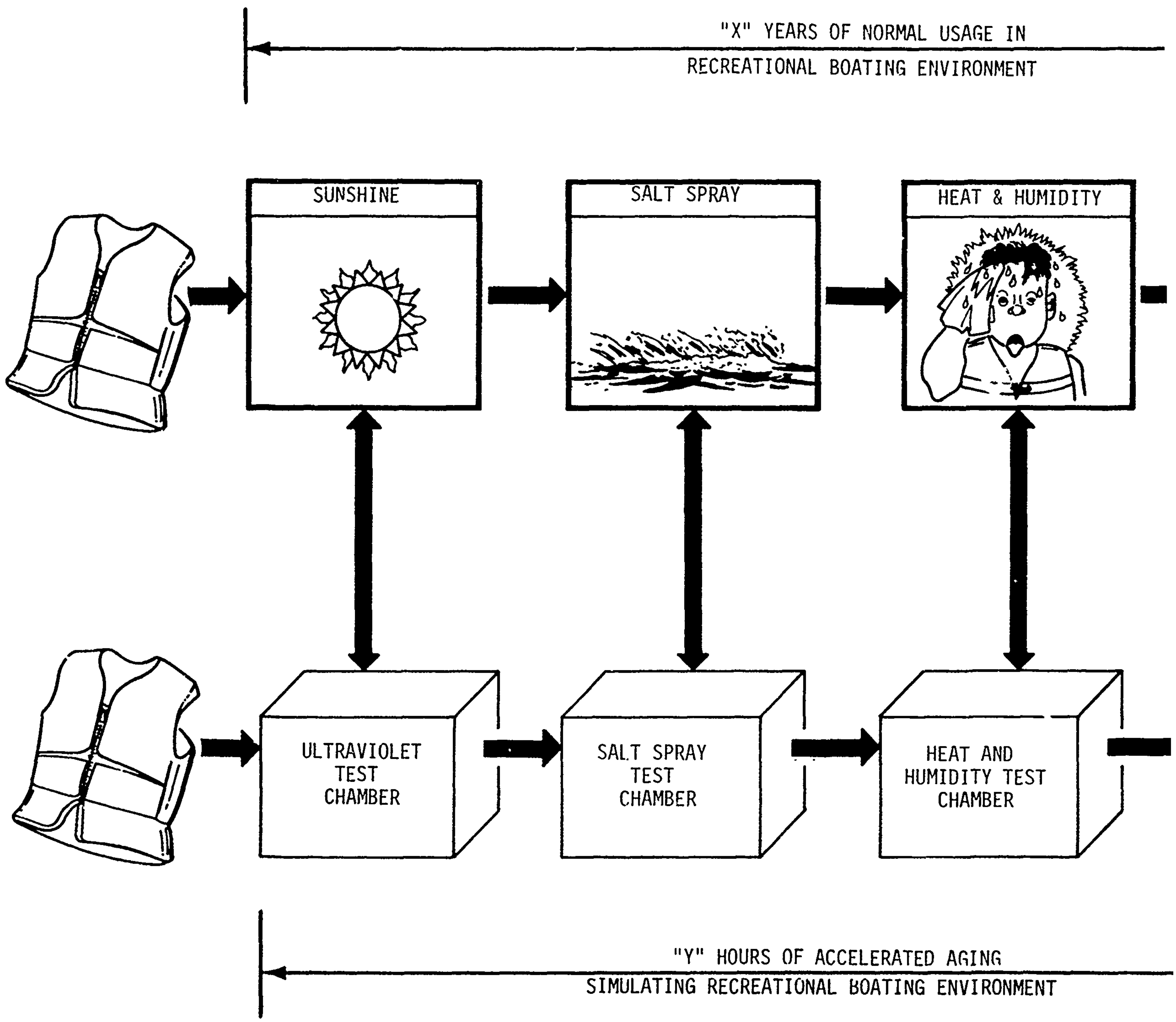
An Accelerated Aging Test Sequence was developed which is applicable to inherently buoyant PFDs using foams as the flotation material, and to inflatable and hybrid PFDs. Further research should be undertaken to validate these test methods and to cover kapok PFDs. The test results of PFDs subjected to the Accelerated Test Sequence can be inserted into a Reliability Prediction Model to compute a Reliability Index for use in the LSI.

The scope of the present work did not include the problem of maintainability of PFDs. The ability of a consumer to be able to recognize when a product has reached the end of its useful life or that a failure is imminent is important. The degree to which a particular type of PFD will display either a failure mode or end of useful life characteristic varies. This aspect of PFD use and its impact on the reliability of the PFD population currently in use needs to be considered in future work. The reliability indices estimated here for inflatable and hybrid PFDs assume that the devices have not been previously actuated, or that if they have been previously actuated, that the users have replaced the CO_2 cylinders or other expendable components.



ACCELERATED AGING OF PFDS IN ARTIFICIAL SUNSHINE

4 224.1.


"X" YEARS OF NORMAL USAGE IN
RECREATIONAL BOATING ENVIRONMENT
SUNSHINE
SALT SPRAY
HEAT & HUMIDITY
ULTRAVIOLET TEST CHAMBER
SALT SPRAY TEST CHAMBER
HEAT AND HUMIDITY TEST CHAMBER
"Y" HOURS OF ACCELERATED AGING
SIMULATING RECREATIONAL BOATING ENVIRONMENT

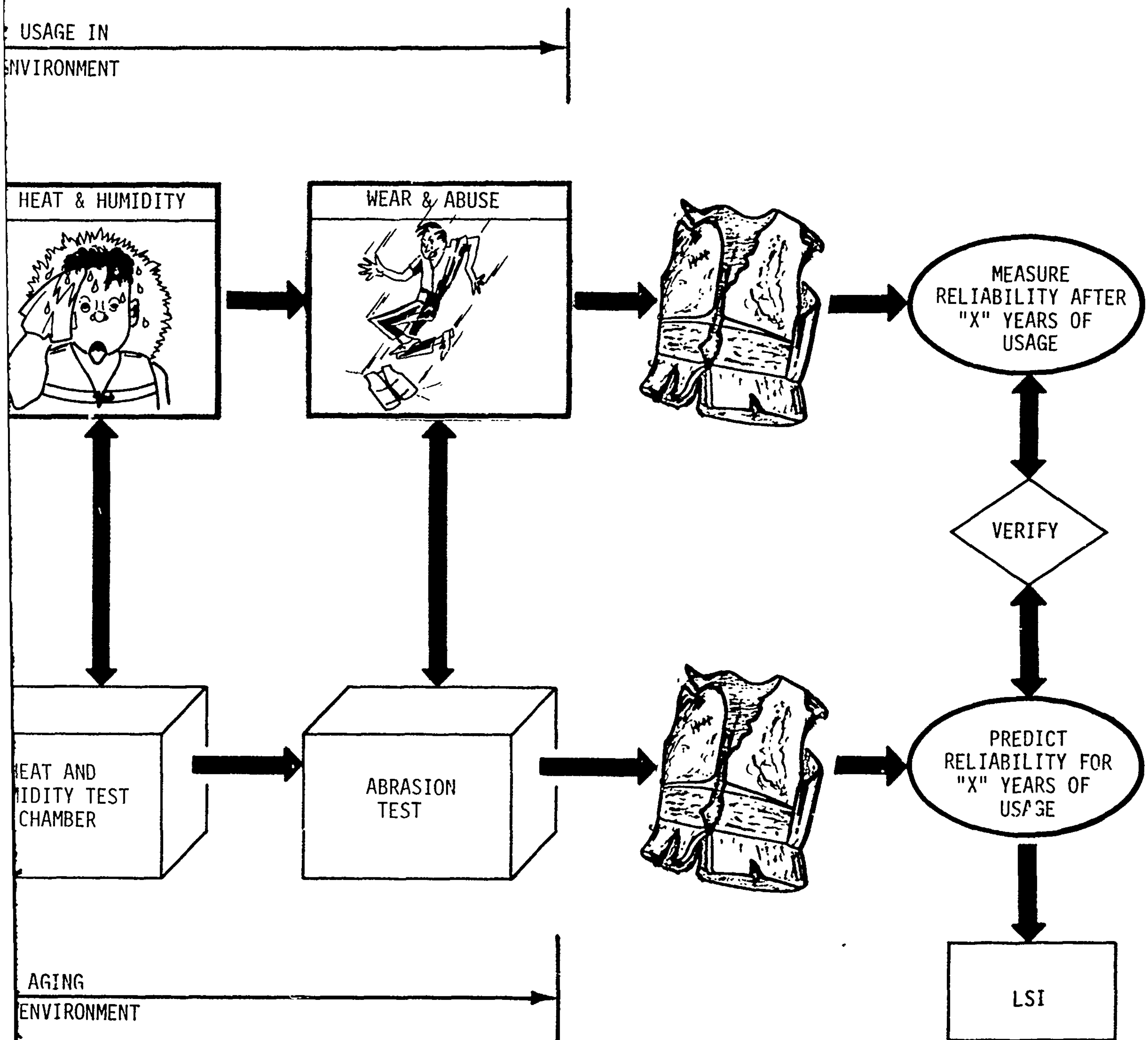


FIGURE 6. METHODOLOGY FOR PREDICTING
PFD RELIABILITY

SECTION 6.0
THE ACCIDENT RECOVERY MODEL

The Accident Recovery Model (ARM) has been developed as an analysis tool, with related techniques and procedures that organize and summarize accident data, so that the role of personal flotation devices in saving lives can be evaluated and the impacts (in terms of reducing fatalities) of existing and proposed regulatory and educational programs can be assessed. The discussions in Section VI, Volume 2 demonstrate how ARM has fulfilled its dual purpose.

The basic results reported indicate that the ARM data base is representative of the Coast Guard's data. The basic results also indicate problem areas in recreational boating. These were identified by the low probabilities of recovery corresponding to victims in parts of ARM. The detailed analyses revealed significant interrelationships between accident variables and their effects on a victim's chances for survival. Although the majority of the examples involving ARM deal with PFDs, the model has been designed so that it can be used to analyze data pertaining to almost any part of the recovery process. For example, loading problems may be identified by the number of persons on board versus boat length for various boat types. Problem areas are easily identified, such as the fact that the probability of recovery for a victim from a manually operated craft is very low (58%) compared to all other types of power (94%).

It is shown that ARM can be used to measure the relative importance of PFD properties such as self-actuation of inflatables, the ability to turn an unconscious wearer, the quality of being highly wearable, and effectiveness and reliability over time. For example, it is shown that: 1) there is very little evidence of a reliability problem with PFDs in the accident data, and 2) nearly three-fourths of the fatalities and recoveries for whom time in the water is known occur in the first 15 minutes. Thus, it appears that a PFD can save many lives if it is worn, it may not need to function for a long time (especially with the advent of level flotation in the future), and hypothermia protection may not be of great importance in a great number of cases since fatalities and recoveries occur in such a short time.

ARM is used to generate quantitative estimates of the benefits of hypothesized and actual changes in recreational boating (changes in PFD wear, changes in PFD properties, i.e., the Life-Saving Index, educating boaters to stay with their boats, and the effects of hypothermia and level flotation).

The benefit estimation technique used with the ARM data is called "multi-state" analysis. The need for this type of analysis arises from the complicated interrelationships between recovery variables. If the probability of recovery for PFD users (0.914) is compared with the probability of recovery for PFD non-users 0.911) overall, there seems to be very little improvement with PFD use. However, upon further analysis, it can be shown that the PFD users are in more severe circumstances (rougher water conditions, in the water as opposed to in the boat, etc.). Unless the benefit estimation analyses account for the biases introduced by these more severe circumstances being associated with PFD use, the results will be artificial and misleading. Multi-state analysis does take these other factors into account. Benefits are computed in each of several circumstances (severe and non-severe) and then summed to produce an overall benefit estimate. Thus, although there is little change in the overall probability of recovery with PFD use, it can be shown that a large number of lives are being saved by using PFDs (approximately 100 lives per year currently). The need for the multi-state benefit analysis is due to the intrinsic nature of accident survivability, which depends upon the complex interrelationships of several factors. Thus, the ARM benefit estimation technique allows the analyst to not only determine the potential benefits of his program, but also to include the effects of other related recovery measures and how his program will affect them. ARM can be used to evaluate existing programs and standards or proposed ones, or combinations of programs.

It should be noted that the benefit estimates produced by ARM tend to be conservative. There are unknowns in ARM for many variables. Often the unknowns have a higher probability of recovery than any known group. Also, there are many unreported recoveries from accidents each year. The unknown and unreported recoveries mean that most of the probabilities of recovery in ARM are lower than the true probabilities, especially in the circumstances where recoveries are likely to occur. This means that more recoveries do occur than those estimated by ARM, and more would occur than those shown in the benefit estimates. Thus, it is likely that a program showing positive benefits in ARM, actually would be saving more lives than the benefit estimate would indicate.

Finally, a statistically significant linear relationship was found between the average Life-Saving Index for the PFD population and the estimated benefits (lives saved) from PFDs. This relationship makes it possible to estimate the effects of changes in PFD parameters (wearability, accessibility, reliability, and effectiveness) on a victim's chances for survival. Basically, the relationship shows a benefit of approximately 8.8 lives saved for each 0.01 increase in the average LSI.

A graphical representation of the chronology of the Accident Recovery Model development is presented in Figure 7. Inherent in this chronology were:

- The development of ARM was an iterative process, based upon empirical data.
- The ARM Analyst's Guide was written, along with needed computer programs.
- The ARM sampling and weighting plan was designed to represent an "average" year.
- The data were coded independently, verified by computer and analysts, and reviewed by senior project personnel.
- The sampling and weighting plan was verified, the representativeness of the ARM data was checked. The results were analyzed, variable by variable, for the entire ARM data base.
- Variable interrelationships were explored, results were provided for other parts of the PFD project, and complex analysis techniques were developed and used to evaluate the role of PFDs in boating accidents and the impacts of various existing and proposed USCG programs.
- ARM was designed to be general, and therefore can be used to provide benefit estimates for a wide variety of programs, including those not related to PFDs. The analysis techniques that have been developed include accounting for not only the main effects of a program, but also the more subtle interactive effects with other programs and recovery measures.

- ARM benefit estimates have been shown to be conservative (low), due to underreporting of non-fatal accidents, in cases where the contemplated action results in a positive benefit prediction from ARM.

In the future, as more accident data are coded into ARM, the expanded data base can be used to answer a multitude of questions, to indicate areas where research and/or safety measures are needed, and to evaluate past and proposed programs and actions.

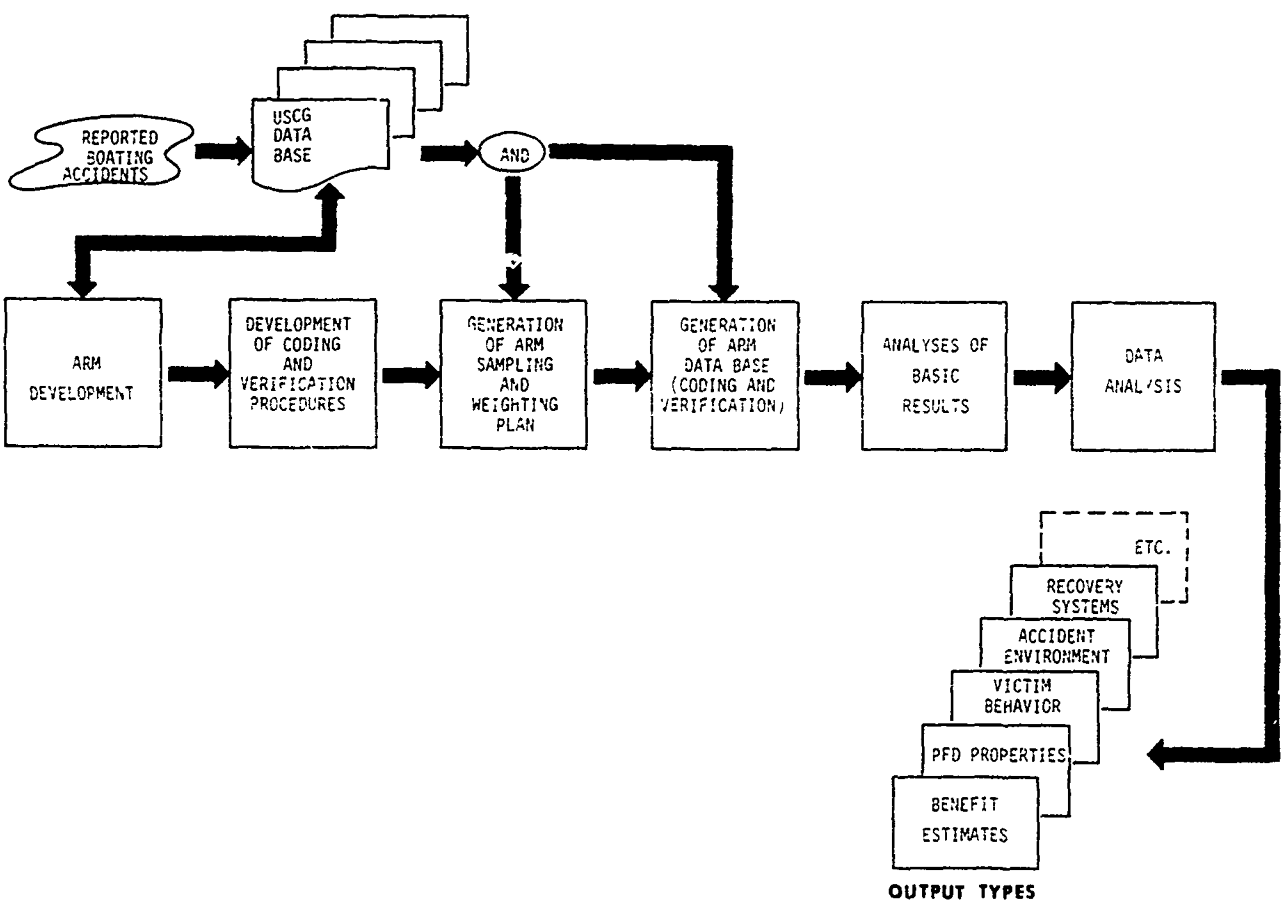


FIGURE 7. CHRONOLOGY OF PROGRESS FOR THE ACCIDENT RECOVERY MODEL (ARM)

SECTION 7.0

ANALYSIS OF THE LIFE-SAVING INDEX SYSTEM

Section VII, Volume 2 is concerned with the application of the LSI to the PFD approval process.

7.1 Calculation of LSI Values for Existing Devices

Section VII starts with a review of the LSI, a description of its application to three accident scenarios, and a presentation of the overall LSI which is a weighted combination representing the following three scenarios:

- Case A: The accident victim is unconscious or incapacitated upon entering the water.
- Case B: The victim is conscious upon entering the water but becomes unconscious while in the water.
- Case C: The victim is conscious and remains so while in the water.

Next, justification is given to:

- Not requiring a priori use of automatic actuators on inflatables. Instead, due to the present reliability problems with automatic actuators coupled with the relatively few cases where automatic actuation would result in additional lives saved, we recommend that the overall LSI be defined such that the capability to automatically provide buoyancy increases the overall LSI. Further work on automatic actuators is recommended.
- Not requiring a priori hypothermia protection or unconscious wearer righting capability (although to achieve the minimum acceptable LSI which we recommend, the manufacturer may choose to provide these capabilities).

Although it is recommended that automatic actuation and righting moment not be a requirement for all PFDs evaluated under the LSI System at this time, <u>these capabilities are reflected in the value of the LSI</u>.

Table 1 shows LSI values for typical devices currently in the marketplace as well as inflatables and hybrids which could be built based on modifications to devices already in the marketplace.

The following important points emerged from this work:

- The research indicates that Type II yoke devices, which in 1975 comprised almost 50% of the available devices in use, has an overall LSI of only 0.11, as opposed to over 0.25 for some inflatables, and 0.24 for a Type III vest.

- The reliability index of feasible inflatables actually exceeds that of many presently approved devices.

- Hybrids (one of which is Coast Guard approved) have the highest overall LSI of currently available devices.

- The research indicates that it should be possible to allow future approval of inflatables with life-saving capabilities twice that of Type II yokes and having individual wearability, reliability, and effectiveness indices also higher than the corresponding indices for Type II yokes.

7.2 Cost and Benefit Analysis

Two alternatives for implementing the LSI System are presented. Neither is meant to be an optimum approach. They are examples meant to show the utility of the LSI System and further analysis by the Coast Guard should identify more effective approaches. The first approach we analyzed simply involves removing the present Coast Guard prohibition against approval of high LSI inflatable and hybrid devices. It would result in a minimum expected benefit of 48 lives per year if applied to the adult population alone. The option allows a manufacturer to submit his device for "Type X" approval using the LSI System. Therefore, it allows a wider variety of high life-saving effectiveness devices to enter the market if the public desires them, but does not force anyone to buy a higher potential, but possibly more costly, device than the inexpensive AK-1. The 48 lives per year benefit figure assumes Type X devices enjoy a market reception on the order of the reception given the Type III (the costs for Types Xs and Type IIIs would be similar). If the Type X certification program was extended to

TABLE 1. LSIs FOR CURRENTLY APPROVED DEVICES AND TYPICAL INFLATABLES AND HYBRIDS

TYPE OF PFD	WEARABILITY INDEX I_W	PROBABILITY THAT PFD IS ACCESSIBLE TO VICTIM BUT NOT WORN INITIALLY UPON ENTERING THE WATER I_{AC}	PROBABILITY THAT AN ACCIDENT VICTIM IN THE WATER SUCCESSFULLY DONS THE PFD GIVEN THAT IT IS ACCESSIBLE, RELIABLE, AND NOT DISCARDED P_D[11]	PROBABILITY THAT AN ACCIDENT VICTIM IN THE WATER LIES UPON OR HOLDS THE PFD GIVEN THAT IT IS ACCESSIBLE AND RELIABLE P_H[11]	EFFECTIVENESS IN PROVIDING ≥4" FREEBOARD AND MAINTAINING RELAXED WEARER IN HEAD-BACK POSITION E_{W_C}	EFFECTIVENESS IN TURNING UNCONSCIOUS WEARER TO POSITION WITH ≥4" FREEBOARD (MOVING TEST) E_{W_B}	EFFECTIVENESS IN TURNING UNCONSCIOUS WEARER TO TO POSITION WITH ≥4" FREEBOARD (STATIONARY TEST) E_{W_A}	EFFECTIVENESS WHEN HELD OR LAIN UPON IN THE WATER E_{H_C}	RELIABILITY AT THREE YEARS OF AGE R	RELIABILITY IN AUTOMATICALLY PROVIDING BUOYANCY AT THREE YEARS OF AGE R_A	OVERALL LIFE-SAVING CAPABILITY LSI
Type II yoke[1]	0.07	0.13	0.57	0.13	0.94	0.40	0.00	0.71	0.9800	0.9800	0.11
Type III vests	0.30[1]	0.07	0.50	0.20	0.94	0.07	0.00	0.30	0.9790	0.9790	0.24
Type III flotation jacket	0.37	0.00	0.29	0.41	0.94	0.00	0.00	0.57	0.9790	0.9790	0.27
Type IV rings/ horseshoes	0.00	0.44	0.00	0.70	0.00	0.00	0.00	0.57	0.9825	0.9825	0.13
Type IV kapok cushions	0.00	0.53	0.66	0.04	0.50	0.20	0.17	0.30	0.9999	0.9999	0.15
Yoke/Collar type inflatable	0.35[2]	0.05	0.66	0.04	0.78	0.67	0.28	0.51	0.9835	0.00	0.25 }
Belt type inflatable	0.35[7]	0.06	0.57	0.13	1.00	0.00	0.00	0.30	0.9366	0.00	0.28 } .29
Hybrid vest with about 15 lbs inherent buoyancy	0.30	0.18	0.31	0.39	0.94	0.80	0.00	0.67	0.9999	0.96	0.32 }
Hybrid vest with about 10 lbs inherent buoyancy	0.35[3]	0.02	0.33	0.37	1.00	0.73	0.00	0.83	0.9941	0.38	0.30 }

[1]AK-1 device

include children's devices, an even higher benefit could be expected. Furthermore, the benefit of 48 lives per year assumes the use of technology presently in the marketplace. Using technology readily available to the industry, but not currently used by the industry, doubling or tripling of that benefit could be easily achieved. It is important to remember that the benefit accrues entirely through the removal of present constraints on the market posed by the present approval system's inability to allow the approval of high LSI inflatable and lower fixed buoyancy hybrid devices.

This Type X approach is an extension of the approach already used in the establishment of the Type III approval. The Type III devices had lower physical effectiveness capabilities than the Type I and II devices, but higher wearability indices. As discussed in Section VII of Volume 2, the Type III regulation appears to have been saving 20 lives per year in 1975, only three years after its implementation.

The other implementation approach presented would involve approving only devices having an LSI of at least 0.23. All devices would be approved under the LSI System and the current Type I, II, III, IV, and V approvals for recreational boats would be eliminated. This would result in the elimination of Type II yokes and Type IV cushions as we know them. The consumer would be forced to replace these devices as they wear out with more expensive Type IIIs, inflatables, or hybrids. Using present production cost figures and assuming no technological progress, a cost per life saved of $497,000.00 for this approach was calculated. That cost is more than the Coast Guard has considered to be justifiable in the past. It should be noted that better device cost data and design information from Phases III and IV may change the cost benefit viability of this approach in the future. Due to the high cost per life saved of this minimum 0.23 LSI for all devices approach, the Type X approach is recommended at this time.

One advantage of the Life-Saving Index System is that it has the potential of providing significant consumer information on the value of his flotation device. While a number such as 0.25 may be selected for the minimum LSI for Type X, the Coast Guard may choose to have classes within Type X of higher LSI devices. As an example:

Type	Minimum LSI
XC	0.25
XB	0.30
XA	0.35
XAA	0.40
XAAA	0.45

could be used whereby manufacturer's advertising and Coast Guard education could be used to inform people of the availability of higher LSI devices. This consumer information would help the manufacturer who chooses to build a high LSI, but possibly more expensive, Type X device as well as the more imaginative manufacturer who may be able to achieve a "breakthrough" with a high LSI, inexpensive device using new materials or actuator technologies. If the above was implemented and technological breakthroughs achieved, a significantly greater benefit than 48 lives per year could be realized.

Next we present an analysis of three alternative approval/certification procedures for the Coast Guard to consider, and the costs for each are estimated. In all cases, the LSI System cost is comparable to that of the current system. The cost of the Type X approval is in each case comparable to the present approval system.

A discussion of the effects of a recovery system including both level flotation and advanced PFDs is given. Sources of both a) possible "double counting" of benefits and b) synergistic benefits resulting from both the concurrent use of both systems but not presently counted by either program are discussed. It is shown that nearly twice as many accidents may be uncounted, due to synergistic effects, as may be double counted. The effects of level flotation on PFD requirements are discussed in detail, and particular attention is given to the point that: if the level boat is the primary recovery mechanism, the PFD may need only to serve for long enough to enable the victim to return to the boat. This may result in lesser PFD buoyancy requirements, less requirements for PFD hypothermia protection, and less requirement to support an unconscious victim.

The full degree of PFD-level flotation interaction cannot presently be analyzed by ARM, due to lack of level flotation boats in the historical data base. A more complete analysis using 1978 accident data (which should contain some level flotation boats) is recommended. As noted above, on balance we feel that our benefit estimates for the Type X approval are conservative in view of the synergistic effects of level flotation coupled with more wearable PFDs.

In summary, this section builds a solid case for the "applicability" of this research within the Coast Guard's PFD approval process. With additional study, it is likely that a more effective means of implementing the LSI concept to save lives will be identified. Our effort to date has concentrated on developing a technology applicable to a more flexible PFD approval procedure. Future phases of the PFD project should be concerned more deeply with optimizing the use of that technology in the Coast Guard's operational PFD approval program.

The preceding chapters (see also Sections III-V of Volume 2) amply demonstrate the feasibility of all the components of the LSI System. Practical, efficent, and accurate methods are presented to predict PFD wearability/accessibility (originally rated as the highest risk area), effectiveness, and reliability. The areas with the greatest need for further development are alternative methods for implementing the LSI System, and PFD effectiveness (extension of the present procedures to rough water, PFDs for children, to account for subject's clothing, and to refine the dummy approach). The LSI System and its component test procedures involve minimal, if any risk for further development. However, most of the areas require further refinement and validation as detailed in the next section.

SECTION 8.0

PERSONAL FLOTATION DEVICES RESEARCH - PHASES III AND IV: ADVANCED DEVELOPMENT PROJECT PLAN

This chapter presents a proposed project plan for completing the PFD project. Two phases are proposed:

Phase III - Advanced Development

Phase IV - Implementation Analysis and Final Development Including Prototype Devices

Included in this chapter are:

Section	Description
8.1	Background
8.2	Objectives
8.3	Scope
8.4	Approach, including Task Descriptions
8.5	Schedule and Resources Requirements

It should be noted that the exact content of some of the tasks described herein, and in some cases even the desirability of performing them, hinge on the result of analysis tasks proposed at the start of each phase. These interrelationships are described in Section 8.4.

PROPOSED PROJECT PLAN

8.1 Background

The purpose of this effort is to establish performance-oriented methods and models for the evaluation of personal flotation devices (PFDs). These methods are to be both comprehensive and flexible. They shall encompass all the aspects of PFD performance related to a PFD's life-saving potential, including wearability, accessibility, effectiveness, and reliability. They must also be applicable to diverse types of PFDs in order to foster the development of innovative designs which lead to higher life-saving potential.

Test methods and mathematical models for the evaluation of PFD effectiveness, reliability, wearability, and accessibility have been established as the result of previous research and development work. These test methods and models are designed to predict the actual performance of candidate PFDs in the recreational boating environment. The capability to accurately forecast performance in real-world conditions makes it possible to compare diverse PFD designs on a common scale of life-saving capability. A single number, called the Life-Saving Index (LSI) is determined for each type of PFD. The LSI is the predicted probability that the candidate PFD will prevent the user of the device from drowning. The test methods and models which make up the LSI evaluation procedure have already been applied to predict the performance of a variety of inflatable, inherently buoyant, and "hybrid" PFDs. The results help to dispell some common misconceptions about PFDs. For example, some kinds of inherently buoyant devices are highly wearable under certain conditions. There are simple and inexpensive inflatable PFDs whose reliability and effectiveness compare favorably with inherently buoyant types.

Before they are implemented, the test methods and models which comprise the LSI procedure should be validated and refined. The methods must also be extended to cover certain areas with special requirements, including children's PFDs and rough water conditions. To date, most of the PFD research has centered on the development of a technology for evaluating the lifesaving potential of a wide variety of PFD designs. While two possible means of utilizing that technology in the Coast Guard's approval process have been identified, no attempt at optimizing the system has been used. In view of public, industry concerns, and Coast Guard resource constraints, this optimization must be a critical part of the Phase III work.

8.2 Objectives

1. Validate the test methods for measuring effectiveness, reliability, wearability, and accessibility by collecting both field data and laboratory predictions for representative types of commercially available PFDs which are suitable for use in recreational boating activities.

2. Use information from the Coast Guard's Hypothermia project and in-depth analyses of boating accidents to develop better estimates of parameters in the LSI and parameters which influence the implementation plan for the LSI System. Particular attention should be given to the LSI weighting factors.

3. Use the information gathered in Objectives (1 & 2) to refine the test methods and associated mathematical models to insure the highest practical level of accuracy. Also establish statistical confidence limits on the accuracy of the LSI and associated performance parameters, including reliability, effectiveness, wearability, and accessibility.

4. Insure the applicability of the LSI to devices not currently available in the marketplace. This should be accomplished by obtaining advanced devices in cooperation with industry, or actual design and fabrication of devices if necessary, and subsequent evaluation and testing of the devices to validate the LSI System and close any possible "loop holes."

5. Extend the LSI test methods and models to encompass the performance of PFDs in rough water conditions and PFDs for children.

6. Evaluate probable boater response and potential problem areas in the implementation of the LSI procedures and recommend solutions.

7. Assess the need and develop guidelines for periodic revalidation of the LSI and its associated test procedures.

8. Optimize the system for applying the work within the Coast Guard's PFD approval system in view of the safety, technical, public, industry, and experimental concerns and constraints.

9. Analyze effects of service dependency on the LSI, and the desirability, costs, benefits, and feasibility of service-dependent LSI equations and carriage requirements.

8.3 Scope

The scope of this project shall be to refine, validate, and extend the PFD evaluation methods and models developed in PFD research, so that these procedures are ready for trial implementation and evaluation.

The scope shall also include the evaluation of boater and industry response to the new procedures and its effects, and an analysis of potential implementation and validation problems.

8.4 Approach

The advanced development of test methods and models for PFD evaluation will consist of two phases and ten tasks. Phase III includes Tasks 1 through 4 and Phase IV is Tasks 5 through 10.

PHASE III

Task 1 - Program Analysis and Preliminary Implementation Analysis

This task will concern itself with the acquisition and analysis of better accident data to support decisions concerning the LSI System. This will include the following:

a) A sensitivity analysis of the LSI to determine limits on the required accuracy of the various LSI parameters and to re-evaluate the priority of tasks aimed at improving our predictive capability for evaluation of the parameters. A sensitivity analysis plan should be submitted as soon after the start of this task as possible for approval by the Coast Guard.

b) Utilization of better Hypothermia data from the Coast Guard's Hypothermia Project and analysis of its impact on parameters in the LSI.

c) In-depth analysis of cases where PFDs were used, but fatalities resulted, to aid in finalizing the Effectiveness Model. This coupled with the sensitivity analysis will result in a decision as to the necessity for rough water testing.

d) In-depth analyses of the impact of accident recovery factors on the PFD benefit estimates an analysis of how such factors affect the LSI. The factors whose impact shall be evaluated include:

1. level flotation
2. the number of boating accident victims annually who are unconscious or incapacitated when they enter the water
3. the proportion of accident victims, entering the water, who hold or don an accessible PFD

The analyses should use the case-by-case empirical approach similar to that used by Kissinger (Reference 1) and/or a statistical analysis of 1978 accident data if that data contains sufficient information about the factor being investigated.

e) An update of the benefit estimates and adjustments of LSI parameters based on the above.

f) As part of this work, potential alternative approaches to the implementation of the LSI evaluation procedure will be identified. Problem areas such as industry response, consumer reaction, and limited Coast Guard resources should receive special emphasis. This subtask should address new ideas for complete or partial implementation, and identify portions of the LSIs testing procedure which might be used to improve the present Type I through V approval program. Solutions to the identified problem areas will be recommended where possible. The need and guidelines, if necessary, for periodic revalidation of the LSI and its test procedures will be assessed. The assessment of need for periodic revalidations shall be based upon costs and benefit analyses. The possible impact of the LSI System on carriage requirements and recommendations for changes in these requirements will be made.

Task 2 - Calm Water Effectiveness

Subtask a - Clothing

This task will first deal with the problem of allowing sufficient buoyancy to float clothing in addition to the minimally clothed victim included in the present model. The "clothing allowable" will be determined by:

a) Generating clothing profiles using pictures from the observational study (from Phase I).

b) Including quantity of clothing as an additional parameter in the dummy validation tests which will be described next. This should lead to a recommendation for the quantity of clothing, or other modification, to be put on the dummy to make it represent a clothed victim.

Subtask b - Effectiveness Calm Water Test Procedure Validation

In Phase II, it was shown that a dummy could be used to closely represent the population at large during calm water righting moment tests. The dummy test procedure needs to be extended to use dummies to represent specific percentile ranges of the population. However, such a dummy design, fabrication, and validation program would be quite expensive. At this stage, in conjunction with the sensitivity analysis in Task 1, an analysis of the possible error bounds involved in human subject testing vs. dummy testing of PFDs should be made and the necessity for a dummy development project re-evaluated.

Task 3 - Reliability of Inflatables and Hybrids

The purpose of Phase III Reliability Research for inflatable and hybrid PFDs is to extend and validate the approach and recommendations derived from past research, so that assurances can be made as to the adequacy of the Accelerated Test Sequence in generating a Reliability Index which is representative of actual performance in the recreational boating environment.

Advanced development work shall include the following components:

1. Solicit industry's participation to submit lot samples for testing to the accelerated sequence.
2. Those lots which receive an acceptable Reliability Index, based on the results of the Accelerated Test Sequence, would be subjected to actual use conditions in a controlled experiment using a pre-selected, qualified group of subjects, such as Coast Guard Personnel, BOSDETS, contractor personnel, or other easily accessible sources.
3. All PFDs used in Step 2 would be collected and tested after a pre-determined period of time and any accidents would be investigated.

4. The results of actual usage would be compared to the Reliability Index. Modifications would be applied, as required, to the Accelerated Test Sequence and Reliability Index Model using the inputs from the results of the actual use test.
5. Establish minimum performance standards for automatic inflation systems which assure satisfactory real-world performance for affordable automatic inflators.

Task 4 - Wearability/Accessibility

Additional data on PFD wearability and accessibility shall be gathered to validate and extend the wearability/accessibility model and test method. The validation tests should include observations to determine the actual wear rates for selected PFDs in the field. The augmented sample must be representative of geographic areas, climates, and boating activities in the continental United States. The sample must also encompass children, so that we can evaluate differences in present PFD wear rates for children versus adults. A field study of PFD wear and accessibility of present and advanced devices for children will be conducted under Task 7. The cost of including children in the observational study is relatively small and considerably smaller than conducting a separate investigation later. Therefore, children have been included in this task even though the extension of the LSI System to children is otherwise in Task 7.

PHASE IV

Task 5 - Rough Water Effectiveness and Reliability

The full extent of this task, or even the need for it, cannot be fully determined without the completion of portions of Task 1. Therefore, it has been included in Phase IV of the project schedule (Exhibit 1). In order to cost this task, the assumptions were made that rough water conditions will be required, but they will be limited to "second order" considerations i.e., they should be included in the model, but the accuracy of the rough water effectiveness numbers need not be as great as for calm water. This assumption is supported at present by noting that 60% of the cases are in calm water or swift currents and that "rough' was coded whenever any low current environment other than absolute calm was indicated on the BAR.

This latter assumption allows us to handle the rough water PFD dynamics by empirically relating rough water capability to a calm water test parameter. As an example, we may attempt to use calm water freeboard, buoyancy, or calm water righting moment as indicators of rough water capability. This could be accomplished by performing rough water testing using human subject and analyzing the ability of various easily measured (in calm water) parameters to predict the PFD performance in rough water. The definition of "rough" water has to come from the analysis completed in Task 1 and the state of the victims (conscious vs. unconscious) would come from ARM data as modified using data from the Coast Guard Hypothermia Project (see Task 1).

Task 6 - Advanced Implementation/Analysis

This task is the principal task for Phase IV, and it is responsible for establishing the direction of Tasks 7 and 8. This task is responsible for generating alternative implementation approaches for Coast Guard selection. Once the Coast Guard's decision is made, the need for Tasks 7 and 8 will be established. If the Coast Guard decides to apply the LSI System to children's devices, then Task 7 must be completed. If the LSI System is to be applied to all devices or if the present Type I, II, III, IV, and V approval procedures are to be modified as a result of this work, then Task 8 should be completed.

Task 7 - Extension of LSI System to Children

This task will develop test procedures for extending the reliability and effectiveness parameters to cover children.

Task 7a - Extension of Effectiveness Test Methods to Cover PFDs for Children

Criteria for effective PFD performance for children shall be determined, giving special consideration to behavioral factors which affect PFD utilization by children. The effectiveness of representatives of each major type of PFD shall be determined with a sample of human test subjects. Special attention must be given to the sample size and representativeness in order to make the estimates of effectiveness as accurate as possible within budgetary constraints. The data from human subject testing shall be used to extend the test methods and model developed in previous research to predict effectiveness parameters for children's PFDs.

Subtask 7b - Reliability

Modifications will be made to the test procedure or specifications for reliability to include provisions for inflatable PFDs for children. The approach will be similar to the approach used for adults, with any possible differences for children identified and appropriate tests conducted.

Subtask 7c - Wearability

Using differences in observed child and adult wear rates from the Task 4 observational study, field tests of wear rates for children will be conducted, if required, and a separate child wear/accessibility model and test procedures developed.

Task 8 - Reliability of Inherently Buoyant Devices

Under past PFD research on inherently buoyant PFDs, an accelerated aging methodology and reliability test procedures were developed for predicting the reliability of PFDs used in a recreational boating environment. The feasibility of this approach was proven by the development of accelerated aging techniques and reliability test methods that are representative of the recreational boating environment

The test methods developed in past research shall be extended to insure their applicability to all major types of inherently buoyant materials used in PFDs and to all major usage environments.

Advanced development work will address three major problem areas:

1) A determination of the various factors that will affect the reliability of PFDs from boater to boater. Factors such as area of country, amount of boating, type of storage, etc., needed to be considered in order that a "worst case" test methodology can be identified.
2) A validation of the work performed under Phase II by determining how reproducible the results obtained using Phase II test procedures are on other foam materials.
3) The expansion and/or refinement of the test procedures developed under past research to test procedures that can be used on Type I and II kapok PFDs, and Type IV kapok seat cushions.

Task 9 - Advanced Design Development

This task will include the evaluation of the 2-3 advanced PFD prototypes. The criteria for selection of prototypes shall include: (1) the design shall have a high potential LSI, and (2) the designs should anticipate industry development in so far as possible. In order to achieve the latter, the designs and devices should be developed by industry with Coast Guard assistance and encouragement if possible. Actual Coast Guard funded design and fabrication should proceed only if necessary to thoroughly evaluate the LSI System. Preliminary designs, including an analysis and evaluation of their features, could be reviewed in depth prior to the selection of the prototypes.

The prototypes developed shall be subjected to both real-world usage and testing according to the LSI procedures. The results of real-world usage will be compared to LSI predictions to evaluate the validity and accuracy of the LSI test procedures for new PFD designs.

Task 10 - Anthropomorphic Dummy Development

A dummy will be designed which can be easily modified to represent different buoyancy percentile ranges of the adult population. Tests will be performed to determine if the dummy accurately simulates PFD performance with human subjects. An effectiveness test procedure using the dummy, possibly in combination with other approaches, will be recommended.

8.5 Schedule and Resources Requirements

Using the task descriptions contained herein, approximate manhour and materials estimates are generated for each task and are shown in Exhibit 2. The total budget for each task was then computed using an average cost of $55k per man year in Phase III and 60k in Phase IV. The higher Phase IV manyear cost was used to compensate for inflation. A proposed schedule for accomplishing the tasks is shown in Exhibit 1. This schedule is based on the following assumptions:

1. That work begins on Phase III at the start of the fourth quarter FY 78. The completion of many of the projects, then, must be sometime after the summer of FY 79 to allow for summer field tests and the subsequent data reduction.
2. The desirability and scope of Tasks 7 and 8 hinges on the results of Task 6, so a gap between the completion of 6 and the start of 7 and 8 is shown. A one quarter gap is all that is shown as the scope of 7, 8, 9, and 10 can more than likely be decided near mid-completion of Task 6.
3. The Phase IV schedule can be changed in response to resource constraints. Tasks 5 and 6 could be completed concurrently with 1 through 4, or could be delayed. Task 9, particularly, could be included in Phase III, if desired.

REFERENCES

1. Kissinger, J. R., An Analysis of 1974 Fatal Accidents: Predicting the Effectiveness of a Level Flotation Standard, 1976, Report CG-B-1-76.

EXHIBIT 1. TASK SCHEDULE FOR PFD PROJECT - PHASES III AND IV

Phase	Task No.	DESCRIPTION	FY 78				FY 79				FY 80				FY 81				FY 82			
			1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
III	1	Program Analysis and Preliminary Implementation Analysis				X	X	X	X	X	X											
III	2	Calm Water Effectiveness				X	X	X	X	X	X											
III	3	Reliability of Inflatables and Hybrids				X	X	X	X	X	X											
III	4	Wearability/Accessibility				X	X	X	X	X	X											
IV	5	Rough Water Effectiveness and Reliability									X	X	X	X								
IV	6	Advanced Implementation Analysis									X	X										
IV	7	Extension of LSI to Children												X	X	X	X	X	X			
IV	8	Reliability of Inherently Buoyant Devices												X	X	X	X	X	X			
IV	9	Advanced Design Development												X	X	X	X	X	X			
IV	10	Anthropomorphic Dummy Development												X	X	X	X	X	X			

EXHIBIT 2. MATERIALS AND MANPOWER ESTIMATES FOR LIFE-SAVING MODEL ADVANCED DEVELOPMENT

	Task										
	Phase III				Phase IV						
	1	2	3	4	5	6	7	8	9	10	Total
Manyears	1.4	0.25	1.3	1.5	1.0	0.2	1.5	1.3	1.5	0.5	10.45
Materials (includes travel and computer charges)	15k	1k	10k	10k	20k	2k	25k	10k	40	15k	148k