THE DEVELOPMENT OF UNIVERSALLY-SIZED PROTOTYPE LIFE VEST FOR THE FEDERAL AVIATION ADMINISTRATION

By

KARLA LOUISE KNOEPFLI

Bachelor of Science in Home Economics

Oklahoma State University

Stillwater, Oklahoma

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Thesis Adviser

Dean of the Graduate College

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This study dealt with the development of a prototype life vest for the Federal Aviation Administration in Oklahoma City, Oklahoma. The prototype was to provide universal sizing, quick and accurate donning, limited weight and storage, buoyancy, and thermal protection.

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CHAPTER I

INTRODUCTION

Annually, thousands of people fly across the ocean. Eighty percent of the earth's surface is covered with water. "Sixty-six percent of the surface of the ocean has a temperature of less than 25° C, and 47 percent, a temperature below 20° C" (Boutelier, 1979, p. 1). There is a need for a device that will provide thermal protection, as well as buoyancy, in the event of accidental immersion. The military, coast guard, industry, and a number of research groups have recognized this problem and have attempted to develop a device that will extend an individual's survival time.

Current regulations require that flights extending 50 nautical miles from shore provide approved survival equipment for each passenger (Aeronautics and Space, 1981). The Federal Aviation Administration defines approved survival equipment for over water operations in the Code of Federal Regulations (Aeronautics and Space, 1981). The regulations provide that flotation equipment be quickly accessible to all passengers and easy to don in the event of a ditching.

In January, 1982, an Air Florida aircraft crashed into a bridge and landed in the Potomac River. Passengers surviving impact were subjected to water temperatures near zero degrees centigrade. As a result of this accident, the National Transportation Safety Board reviewed the water survival equipment carried on commercial airlines.

This accident renewed an interest in preventing or minimizing the likelihood of hypothermia. The Federal Aviation Administration (FAA) located in Oklahoma City, Oklahoma approached the Department of Clothing, Textiles, and Merchandising at Oklahoma State University in September, 1982, with a design request. The Protection and Survival Laboratory at the Oklahoma City division of the FAA was responsible for evaluating existing water survival equipment and developing new designs. A progress report was to be submitted to the Director of Airworthiness in September, 1983. The FAA wanted the development of a life vest that maintained current FAA specifications yet provided new design features to improve universal sizing, simple donning, and thermal protection.

Purpose

The purpose of this project was to develop a prototype life vest for the Federal Aviation Administration, using the following guidelines:

1. Fit 80 percent of the adult U.S. population
2. Allow for quick and accurate donning
3. Provide thermal protection against immersion hypothermia
4. Maintain FAA buoyancy specifications
5. Meet minimal FAA weight and storage specifications

Significance

Government agencies, such as the U.S. National Transportation Safety Board and the British Department of Trade, are responsible for thoroughly investigating transoceanic flight accidents that occur within their territorial limits. They reconstruct accidents using remaining wreckage, interviewing survivors, determining prior weather conditions, and revisiting the site of the incident. Two conditions consistently cited in reports involving accidental immersion were difficulty in donning survival equipment (Walhout, 1970; Department of Trade, 1981) and immersion hypothermia (Boutelier, 1979). Both have been found to contribute toward the fatality rate of passengers.

The FAA has determined that an adult should require approximately 15 seconds to retrieve and don a flotation device, and 30 seconds to install the device on another passenger. Federal regulations exist which specify the retrieval time, donning time, and buoyancy of water survival equipment (Federal Aviation Agency, 1983). These factors have been found to increase the survival rate of victims involved in accidental immersion. Under circumstances in which a passenger becomes exhausted or is rendered unconscious, the life preserver should support the victim in an upright position preventing the face from becoming submerged.

The FAA has determined there is a direct relationship between donning a flotation device and the survival rate of passengers using water survival equipment. The following paragraphs summarize government reports dealing with immersion and adverse circumstances experienced during accidents at sea.

An aircraft not required to carry life rafts or flotation-type seat cushions crashed at Escambia Bay near Pensacola, Florida in May, 1978, according to the National Transportation Safety report (National Transportation Safety Board, 1978). Life vests were stowed beneath the seats, however, the passenger briefing did not specify the life vests' location, donning instructions, or proper use. Investigations revealed that passengers who were able to locate the life vests had trouble extracting them.

A crash 28 miles east northeast of St. Croix, Virgin Islands in May, 1970, was reconstructed with the aid of survivors (Walhout, 1970). Events, circumstances, and activities surrounding the crash were determined by means of an interview and questionnaire. Passengers indicated they were instructed by the flight crew to locate and don life vests minutes before impact. Those not assisted by the flight crew experienced difficulty locating, removing, and donning the life vests. Investigators suggested that the FAA reassess standards for flotation equipment, passenger briefing, and life vest stowage.

Survivors of an accident near Sumburgh Airport, Shetland Islands in July, 1979, reported as follows.

> Three people donned their life jackets, which inflated correctly, and three others donned them but were unable to inflate them properly... Of the twenty-four survivors who did not use their life jackets, six reported that they were unable to extract them from their respective stowages (Department of Trade, 1981, p.15).

Seventeen persons drowned in water with a temperature of 11° C. Forty-seven passengers survived impact with minor injuries of the face, limbs, or abdomen (Department of Trade, 1981). Passengers reported difficulty locating and removing the life jacket under their seats due to the limited time to exit the plane. The Accidents Investigation Branch of Britain's Department of Trade, concluded that "complete life jacket demonstrations should be given, and individual safety leaflets provided" (Department of Trade, 1981, p. 39).

Three hours after a shipwreck off the coast of Madeira, 113 of 200 passengers were found dead floating in their life belts. The temperature of the calm sea was recorded as 17° to 18° C. "Descriptions given by the survivors and rescue workers pointed to hypothermia as the main cause of death" (Boutelier, 1979, p. 1). These examples point to the need for a flotation device which provides thermal protection and can be quickly retrieved from stowage and donned. Such a device should increase the survival rate of passengers involved in accidental immersion.

Limitations

This project was limited in the following ways:

1. A limited number of prototype life vests were designed.

2. Only materials and hardware currently available in the marketplace were used to develop the prototype life vests.

3. Evaluation of the prototype life vests was performed at the FAA facilities using a convenience sample.

CHAPTER II

REVIEW OF LITERATURE

This project required the development of a prototype life vest for the FAA which met certain prescribed criteria. To accomplish this it was necessary to review the following six areas: Functional design, anthropometrics, federal regulations, donning, thermoregulation, and hypothermia.

Functional Design Process

There are two processes used in designing clothing: fashion design and functional design. The focus of this review is the functional design process, however, each process approaches the development of a garment in a different manner which requires distinguishing between the two processes.

Fashion designs are inspired by history, economics, sociology, and art according to Brockman (1965), Blummer (1981), and Brogden (1971). Brockman (1965) identifies six steps in the fashion design process.

1. The creation of a design with a basic knowledge of style, construction, and materials
2. The experimentation or model development within limitations
3. Style selection through a process of appraisal and elimination
4. Pattern development

5. Production

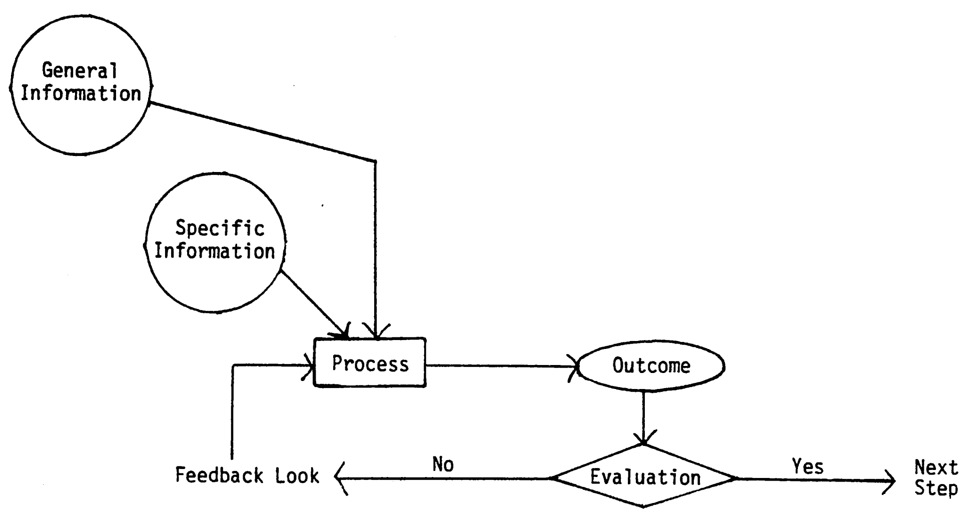
6. Distribution

Brogden (1971) illustrates the fashion design process in a similar but more simplistic way. He describes the designer as receiving a request, discovering possible answers, and evaluating the design through acceptance.

In contrast, functional design requires a more documented and systematic approach. The functional design procedures described by authors in the fields of engineering and architecture are fundamental to all areas of design (W.E. Woodson, 1964). Functional design is a holistic approach (Jones, 1970; Morgan, Cook, Chapanis, and Lund, 1963). It is a method of design which emphasizes the functional relationship between the parts and the whole.

Jones (1970), W.E. Woodson (1964), Morgan et al. (1963), and T.T. Woodson (1966) essentially agree that there are three basic stages to follow in the functional design process. In the first stage a designer is responsible for expanding boundaries (Jones, 1970), identifying limitations (Woodson, 1964) and capabilities (Morgan et al., 1963), and exploring possible solutions as the overall mission of the design is kept in mind (Woodson, 1966). At this stage, no possible alternative is disregarded by the designer. The second stage of the design process organizes the materials revealed in the initial stage into design specifications, objectives (Jones, 1970), and preliminary designs (Woodson, 1966; Morgan et al., 1963). The purpose of this stage is "...to quantify the parameters so as to yield the optimum solution" (Woodson, 1966, p. 25). The final stage of the functional design process is to determine the most feasible solution (Jones, 1970; Morgan et al., 1963; Woodson, 1964; Woodson, 1966). Evaluations may reveal that the solution is acceptable or that previous criteria require reconsideration (Woodson, 1966).

Woodson (1966) subscribes to the premise that a designer seldom achieves a final solution during the first attempt to solve a design problem. He describes a feedback loop that serves as a guide in attempts to solve design problems (Figure 1). This conceptual aid illustrates the input and output of information, the relationship of each procedure, and the sequence of activities completed to achieve the end product.



Source: Woodson T.T. Introduction to Engineering Design. New York: McGraw-Hill Book Company, 1966. Reprinted with the permission of McGraw-Hill publishing.

Figure 1. Feedback Loop

Anthropometry

"Anthropometry, the practice of measuring the parts and proportions of the human body, encompasses a variety of techniques for determining an almost limitless number of dimensions" (McConville and Lauback, 1978, p. III-1). Essential to anthropometrics are reliable data and procedures according to Damon, Stoudt, and McFarland (1966). Using reliable data when designing clothing and equipment increases the possibility for comfort and fit (McCormick and Sanders, 1982) and provides optimal sizing for mass production.

Anthropometrics can be approached in a systematic process. Damon (1966), McCormick (1982), and McConville (1978) suggest: 1) identify the most relevant body dimensions in the design situation, 2) define the population for which the design is intended, and the percentage of the population which the design will accommodate and 3) select anthropometric data based on the previously defined population. McConville (1978) noted that the establishment of size categories is dependent upon the design situation. The data may also require modification to accommodate the design. Modified data are a result of identifying clothing or equipment worn simultaneously with a design, then increasing anthropometric dimensions in terms of fit and function (Damon, 1966; McCormick, 1982; McConville, 1978).

Anthropometric data are applied to design through various methods. McCormick (1982) identified three such methods: 1) design for the extreme individuals, 2) design for an adjustable range of individuals, and 3) design for the average individual. McConville (1978) also used the term "adjustable range" in referring to methods of design, as well as identifying two other more expensive and less feasible methods:

1) "...limiting body size range to fit the design product" (p. VIII-6), and 2) "...the simple design of work space around the individual who will occupy them" (p. VIII-7).

Reliable anthropometric data are essential for design. Such data must be based on criteria established in the early stages of the design process. "Collection of data, in the applications sense, means the gathering and filing of source documents containing anthropometric data in various stages, from raw data to sophisticated condensations" (Roebuck, Kroemer, and Thomson, 1975, p. 197). Data determine design requirements and are used to evaluate a design (Damon, 1966). Damon (1966) described three criteria for determining the reliability and limitations of data. First, the population in question must be adequately represented; second, the sample should be large enough to produce reliable data which can be reproduced in other samples; and third, measuring techniques should be standardized. Similar criteria are described by Roebuck (1975). Collecting an adequate sample representative of a specific population is complicated and involved. Extensive data have been published by government agencies in the United States, Great Britain, Germany, France, and Italy. The United States Air Force, Army, and the Department of Health, Education, and Welfare have published a majority of the data. Reports have also been published by private research groups and industrial organizations (Roebuck, 1975; McConville, 1978).

The human body presents unique design situations since humans vary in size, shape, and weight, each dependent upon race and sex (Annis, 1978). Anthropometric data are an indispensable design tool if properly used. A misleading concept is the use of the average man (McConville, 1978).

> When the average is used in conjunction with some measure of variability, such as the standard deviation, it becomes a useful descriptive tool to specify population parameters. Because the average is a measure of the location of central tendency, it appears logical to assume that it must serve some important role in design, which indeed it does but only when handled with care (McConville, 1978, p. VIII-1).

Therefore, use of averages requires careful consideration.

Percentiles have a more realistic use in design (Damon, 1966). Roebuck stated

> It has become common practice to specify anthropometric design limits and selection standards in terms of statistical numbers called percentiles, which simply indicate the percentage of persons within the population who have a body dimension of a certain size (or smaller) (1975, p. 132).

Percentiles are used to estimate the portion of the population to be accommodated or inconvenienced, permit the selection and accurate use of test subjects, and aid in the selection of operators (Damon, 1966). McConville (1978) said a design should accommodate approximately 90 to 95 percent of the population without compromising design features or credibility. Damon (1966) differed from McConville stating 90 to 98 percent of the population should be accommodated. A successful design should include individuals beyond the design limits, but seldom will it accommodate the extremes without alterations (McConville, 1978).

Although percentiles are useful, they can be misleading if used incorrectly according to Roebuck (1975). The following points should be remembered: 1) a percentile is a point on a cumulative scale for a specified population, 2) a percentile scale is an ordinal scale, 3) anthropometric percentiles on actual individuals refer to one and only one body dimension, and 4) the magnitude of percentile rating should be used to infer exact percentile ratings of other dimensions (Roebuck, 1975). Design seldom involves one body dimension. The use of several dimensions, or determining the relationship between dimensions, complicates defining the population limits (McCormick, 1982).

Federal Regulations

Detailed requirements for life preservers used on board passenger aircraft have been published by the Department of Transportation in Appendix I of the Technical Standard Order (TSO) C13d (Federal Aviation Agency, 1983). The standards prescribed are minimum performance standards governing items such as comfort, fit, materials, design, and testing. The United States government requires that a flotation device provide adequate protection without restricting movement, sight, breathing, or blood circulation (Federal Aviation Agency, 1983).

A life preserver must allow quick and accurate donning for a victim. The FAA has determined that 15 seconds is adequate time to don a life preserver while seated and unassisted, and 30 seconds has been determined as adequate time for installing the device on another individual (Federal Aviation Agency, 1983). The device should be simple to adjust without providing the opportunity for an inadvertent release from the victim, according to Technical Standard Order C13d.

Prior to the takeoff of any flight extending over water, an oral briefing of preparatory procedures shall be administered by a flight attendant. The briefing must include instructions on locating and operating the device. The flotation device must be stowed in a conspicuously marked location and be easily accessible to each occupant (Aeronautics and Space, 1981). If packaged, the device must be retrievable in one operational step. The package shall include illustrated donning procedures and operational instructions with a minimum use of words (Federal Aviation Agency, 1983).

Technical Standard Order C13d specifies materials to be used in the construction of a life preserver. Materials are classified in one of two categories: 1) nonmetallic materials, which include items such as fabric, webbing, and thread; and 2) metallic parts. The FAA has identified specific test methods and specifications to control the quality of materials used to construct life preservers (Federal Aviation Agency, 1983).

Other material standards published in TSO C13d refer to webbing and thread strength. A minimum strength of 230 pounds is required for webbing. Thread used to construct preservers should be size E nylon or have an equivalent minimum strength of 8.5 pounds. Life preserver construction is also addressed in Technical Standard Order C13d (Federal Aviation Agency, 1983).

Construction requirements provide that a flotation device function adequately when reversed, unless there is no probability of donning the device incorrectly. The standards specify that a life preserver allow for not less than two separate gastight flotation chambers. Each chamber shall inflate by means of gas cylinders or oral inflation, and deflate manually (Federal Aviation Agency, 1983). Exposure to temperatures between -40° F to +140° F should have no adverse effect on the life preserver's ability to function correctly according to TSO C13d (Federal Aviation Agency, 1983).

A flotation device should be capable of righting a victim within five seconds and provide support for the victim's head to be in compliance with buoyancy characteristics established by the FAA. The preserver is required to hold the body at a minimum angle of 30 degrees, inclining the trunk and head backwards from a vertical position (Federal Aviation Agency, 1983). This position protects an unconscious victim from drowning due to water being channeled into the face.

Donning

It was previously noted that federal regulations require quick and accurate donning of life preservers. Rasmussen and Steen (1983) and Rasmussen, Chittum, and Saldivar (1984) completed studies involving the retrieval and donning of TSO life preservers. The purpose of each study was to evaluate current and experimental flotation devices certified under Technical Standard Orders C13c and C13d. Life preservers used in both studies were the international rescue color, had two inflatable gas chambers, an oral inflation device, and a rescue light (Rasmussen, 1983; 1984). The first study involved four TSO flotation devices plus two experimental models of modified "Angler Vests" adapted to more closely conform to TSO requirements. The only difference in the two experimental designs was the type, color, and weight of the fabric (Rasmussen, 1983).

Retrieval time, acquisition time, and donning time were defined and calculated by Rasmussen (1983) in the following manner. Retrieval time was calculated "from the sounding of the starting buzzer to the time the packaged life preserver was cleared of its stowed location" (Rasmussen, 1983, p.4). Acquisition time was determined as beginning "when the packaged life preserver was cleared of its stowed location to the time when the life preserver was completely removed from the plastic bag" (Rasmussen, 1983, p. 4). The calculation of donning time began "when the life preserver was removed from the plastic bag to the time when the subject completed final tightening and/or fastening of the attachment" (Rasmussen, 1983, p. 4).

Of the four TSO flotation devices evaluated, it was concluded that "there were significant differences among the four devices with respect to the number of successful donnings achieved at selected time intervals, and in overall donning times for successful trials" (Rasmussen, 1984, p. 6). When the donning times from the 1983 study (Rasmussen, 1983) were compared to those of the 1984 study (Rasmussen, 1984), only one flotation device had a significantly different donning time.

The two experimental models tested by Rasmussen (1983) proved easier and quicker to don than the four TSO devices. Fifty-eight percent of the 50 attempts were completed within 15 seconds compared to one percent of the 100 attempts completed using TSO preservers. This demonstrated that the design of the experimental models was easier to understand and to don. Rasmussen (1983) concluded that correcting design features, which were difficult to understand or manipulate, would increase the performance standards of each life preserver.

Adjustment of a life preserver can be a point of confusion for passengers. Straps contribute to the confusion because they become twisted or jammed in adjustors while being attached and tightened. To reduce confusion, Rasmussen (1983) suggested:

1. An "...attachment and suspension system that would automatically size" (p.9)

2. Simple, single attachment points for items such as straps

3. A device with an obvious front and back

Donning research has also been conducted in the area of clothing for the elderly and handicapped. This research was reviewed for possible design insights that it might yield. In a study conducted by Shannon and Reich (1979), clothing and related needs of the physically handicapped male and female were evaluated. Women and men preferred the jacket, coat, and cardigan styles for ease of dressing. Fifty percent of the women indicated difficulty with garments donned over the head as compared to forty-five percent of the male respondents.

Certain neckline and sleeve styles have been shown to facilitate simple donning and to contribute to comfort. Neckline styles most often identified as least difficult to don were lowered V-necklines, U-necklines (Shannon, 1979), and jewel necklines (Schuster and Kelly, 1974). Individuals surveyed identified the raglan sleeve, kimono sleeve, and sleeveless garments as least restricting (Schuster, 1974; Shannon, 1979). Schuster (1974) found the above-elbow length sleeve to be the most preferred style by elderly women and hospital staff. A study by Shannon (1979) supported this. Shannon (1979) suggested that if full-length sleeves are necessary, elastic cuffs should be applied rather than ribbed cuffs or straight cuffs.

Agility is necessary for donning a garment, and dexterity is required for manipulating closures. The task of dressing is simplified when closures do not inhibit securing the garment to the body. The following clothing features were preferred by the physically handicapped, elderly, and hospital personnel: zipper fasteners, center front closures opening from the neck to the hem, action pleats in the bodice back (Schuster, 1974), adjustable waistbands, elastic, velcro, buttons one inch or more in diameter, and large snaps (Shannon, 1979). Detachable belts or cords are easily lost or damaged (Reich, 1976). Hooks and eyes impair dressing (Shannon, 1979). Reich (1976) reported that the fewer fasteners incorporated into a style, the less difficult it was for a disabled individual to don the garment. Reich also noted that velcro was the most successful all purpose fastener.

A garment closure functions as a mechanism for attaching and controlling a design. Properly designed controls increase the efficiency of a design, provided the following considerations are taken into account (Ely, Thomson, and Orlansky, 1963; Damon, 1966):

1. Movement should be accurate and related to the orientation of the operator.

2. Operation of controls should produce movement in a similar direction.

3. Movement should be natural and consistent with similar designs.

According to Ely (1963) the correct relationship between the orientation of the operator and the direction of movement improves reaction time, decision time, correct use of initial control movement, speed and precision of control adjustment, and learning time. The direction of movement influences the amount of strength inflicted upon the control as reported by Damon (1966). In descending order of strength the following movements were reported: 1) push-pull, 2) rotation, 3) up-down, and 4) right-left. The right-left movement is only about one third as strong as a push-pull movement according to Damon (1966). Therefore, garment closures serve as effective controls to facilitate the donning process.

Thermoregulation

An important consideration in any flotation devise is its ability to assist the human body in temperature control. Heat is necessary for maintaining human life. Survival depends upon a complex mechanism that regulates the core body temperature. A process called thermoregulation maintains the deep body temperature at 37° C (98.6° F), plus or minus 1 to 2° C (1.8-3.6° F) (Collins, 1983; Pozos, and Born, 1982). "Body temperature is an index of what is happening to the heat exchange between the body and the external environment" (Collins, 1983, p. 16).

Heat is exchanged between an object and its surroundings across a medium common to both systems (Collins, 1983). Physical laws governing the movement of heat by means of convection, conduction, radiation, and evaporation account for this heat exchange.

Conduction occurs as heat passes between two objects in physical contact (Fridley, 1978). The heat is transmitted from one body to another through thermal conductors such as metal, earth, and water (Adams, 1978; Collins, 1983).

Convection is the transfer of heat to a cooler object by the movement of fluid across the surface of the object (Adams, 1978; Collins, 1983). The amount of heat transferred between a body and air or water is dependent upon the body temperature, shape, surface, and size (Mount, 1979). A study conducted by Boutelier, Bougues, and Timbal (1977, p. 99) revealed physical factors, such as water velocity and temperature, and physiological factors, such as peripheral vasoconstriction and shivering, influence the amount of heat exchanged by convection between the human body and water.

A third form of heat exchange is radiation. Radiant heat refers to electromagnetic waves transferred from one surface to another (Collins, 1983). The exchange of heat by radiation does not require two objects to come into immediate contact (Kuznetz, 1978) or the movement of air or water across a surface (Collins, 1983).

The process of converting a liquid to a gas (Adams, 1978; Collins, 1983) is evaporation. It is the fourth method of heat exchange. In humans, this process is influenced by the thermoregulatory system through the skin surface, lungs, and respiratory passages (Collins, 1983).

Thermoregulation is a complex biological function involving the cardiovascular, the respiratory, the nervous, and other biological systems (Golden, 1973; Collins, 1983). When the body is subjected to immersion in cold water three simultaneous reactions will occur: "...1) a significant decrease in the heart rate; 2) a vasoconstriction of the blood vessels in the periphery; and 3) an increase in blood pressure" (Pozos, 1982, p. 98). The sudden temperature change restricts blood flow to the skin surface and peripheral areas retaining blood in the head, chest, and groin (Fridley, 1978; Adams, 1978; Collins, 1983).

Hayward, Eckerson, and Collins (1973; 1975) and Boutelier (1977) report that heat production, body size, and body fat interdependently influence heat loss. Heat loss or gain is greater for the individual with greater skin surface area (Collins, 1983). Collins states that the large body, spherical in shape, has greater area for heat loss; but, weight for weight the surface area is greater for the smaller or more linear body shape. This indicates body fat as well as skin surface area effect heat loss. Hayward (1973) found and reported such a relationship between the amount of fat retained in the body trunk and the cooling rate of the core temperature.

The thermoregulatory system is responsible for maintaining the core body temperature under all conditions. Under adverse conditions, such as sudden immersion, survival equipment must assist the body by providing the greatest possible protection from loss of body heat through convection, conduction, radiation or evaporation.

Hypothermia

"Scientists and physicians use the term hypothermia to refer to the subnormal temperature of the body and its physiological condition caused when it is unable to maintain an adequate level of warmth for normal body function" (Pozos, 1982, p. 11). A body's temperature balance can be altered by internal causes such as disease and drugs, or external causes produced by the environment (Collins, 1983; Pozos, 1982). Four general classifications of hypothermia are primary hypothermia, secondary hypothermia, therapeutic hypothermia, and accidental hypothermia.

Primary hypothermia has been described by Collins (1983, p. 31) as an "inherent impairment or disfunction of the thermoregulatory system itself." Age and prematurity are thought to contribute to the development of anomalies in the region of the hypothalamus causing hypothermia in a victim (Collins, 1983).

Secondary hypothermia is a result of some internal cause. Diseases responsible for hypothermia are arthritis, paralysis, heart disease, circulation impairment, and stroke (Collins, 1983). Drugs such as alcohol may also contribute to the onset of secondary hypothermia according to Pozos (1982) and Collins (1983).

Hypothermia can be induced for therapeutic purposes. Therapeutic hypothermia is used in situations such as heart surgery to reduce blood flow (Collins, 1983).

The fourth general classification of hypothermia, accidental hypothermia, results from the unintentional lowering of the core temperature due to exposure to subnormal temperatures (Collins, 1983; Golden, 1972). It can result from exposure to cold air or immersion in cold water (Pozos, 1982).

The most common and dangerous form of accidental hypothermia is immersion hypothermia (Collins, 1983). Water has the capacity to conduct heat away from the body 25 to 30 times greater than air (Pozos, 1982). Immersion of a body in water temperatures lower than the actual body temperature will shock the respiratory and cardiovascular systems causing the victim to gasp (Pozos, 1982). In severe cases the victim may panic causing the swallowing of water or loss of consciousness due to the extreme temperature change (Collins, 1983). Golden (1973, p. 78) identifies major factors influencing hypothermia as:

1. Water temperature and duration of immersion
2. Inadequate protective clothing
3. Amount of body fat
4. Relative amounts of water movement

Surviving immersion hypothermia is dependent on personal and circumstantial factors (Collins, 1983). Studies conducted by Hayward (1975) concluded that altering body posture and then remaining motionless increased survival time during immersion. The effects of five body positions and behavioral variables on cooling rate of man in cold water were assessed. The control behavior consisted of holding still in a standard kapok life jacket and making no attempt to reduce body surface area exposed to the cold water. Drown proofing, a technique in which the individual floats in a relaxed position with the face submerged, increased the cooling rate 82 percent over the control. This was statistically significant at the .01 level. Treading water, the continuous movement of the legs and arms, increased the cooling rate 34 percent over the control. This was significant at the .05 level. However, the cooling rate for treading water was significantly lower than for drown proofing (at the .05 level). The Heat Escape Lessening Posture (HELP), a self huddle behavior which required the subject to press the thighs together and then to raise them against the trunk and hold them secure with locked arms, significantly decreased the cooling rate 69 percent at the 0.01 level. A three person huddling position proved the most effective of the five positions tested. This position required three bodies pressing against one another, thus minimizing the exposure of the lateral thorax. The huddle position significantly reduced the cooling rate 66 percent over the control.

Body posture, flotation equipment, and clothing protect the body against the onset of hypothermia. Life has been prolonged in instances of cold water immersion when a victim has donned a life jacket and protective clothing (Lee and Lee, 1980).

The primary purpose of a flotation device is to provide buoyancy for a victim (Pozos, 1982). Secondary to this is the thermal protection provided by the equipment. A flotation device may delay hypothermia by supporting critical areas such as the head and neck above the water surface (Collins, 1983), or by providing insulation for critical areas of heat loss through design features (Pozos, 1982).

A flotation device and clothing can decrease heat loss experienced in cold water immersion by reducing the movement of water across the skin surface (Pozos, 1982). Under normal circumstances, clothing provides thermal insulation against the elements by trapping air between fibers and layers of clothing (Collins, 1983). With accidental submersion the insulating value provided by the dead air space in dry clothing is lost.

The concept of dead air space has been used to design clothing that will provide thermal protection during immersion. A piece of survival equipment called a dry suit was designed to trap air between the body and a layer of closed cell foam (Collins, 1983; Pozos, 1982). The trapped layer of air is warmed by the body and serves as a layer of insulation (Pozos, 1982). Collins (1983) describes increasing the insulating value of the dry suit by wearing clothing beneath the suit. A disadvantage of this suit is that, if improperly worn, the garment will not restrict the flow of water into the dead air space (Pozos, 1982).

Allowing a limited amount of water to enter the dead air space between the body and fabric is the principle behind the piece of survival equipment called a wet suit (Pozos, 1982; Collins, 1983). The garment is designed to restrict the circulation of water around the body allowing body heat to warm the film of water, creating a layer of insulation. Pozos (1982) noted that the suit is very hot when worn on a day to day basis, and that the suit inhibits movement. The wet suit has been altered to alleviate some inconveniences while retaining thermal qualities. A half body suit was developed using a flap to protect the groin from excessive heat loss (Pozos, 1982).

Hall (1972) conducted a study in an attempt to predict the tolerance time of clothed aircrewmen during cold water immersion. A model was presented that could be used as a guide for developing clothing that provided protection against cold water immersion. The following points were included in the guide:

1. The head is a region of great heat loss.
2. Extremities cool rapidly.
3. Shivering increases heat production and heat loss in cold water exposure.
4. Body size and surface area affect actual tolerance time.

Summary

The FAA has extensively researched water survival equipment. Technical standards have been developed to maintain quality and to ensure the safety of the equipment used by passengers and crew. Present life preservers require design modification to improve current specifications and address new concerns.

Functional design is a systematic approach to design, emphasizing the functional relationship between the parts and the whole. The functional design of clothing or equipment can be facilitated by anthropometrics, the practice of measuring human body dimensions.

Proper comfort and fit are achieved by defining a population and collecting accurate data concerning that populace. The data are used to develop specific styles and features which will enable the quick or accurate use of that device.

The proper fit and comfort of clothing or equipment can also influence the amount of heat transfered between the body and the environment. A process known as thermoregulation maintains the deep body temperature by various physiological responses to external stimuli. Exposure to subnormal environmental conditions can cause the core temperature to drop to an unsafe level causing a condition referred to as hypothermia. Adequate clothing or equipment can reduce the likelihood of hypothermia by reducing the amount of skin surface area exposed or by providing an insulating barrier reducing the heat transfer from the body to the environment.

The review of various disciplines influenced the selection of design specifications necessary for developing a prototype life vest for the FAA. Design characteristics and materials for preliminary designs and the final prototype were selected based on the design specifications.

CHAPTER III

METHODS AND PROCEDURES

The purpose of this research was to design a prototype life vest for the Federal Aviation Administration. The garment was designed to provide universal sizing, comfort, buoyancy, quick and accurate donning, limited weight and storage, and thermal protection. To accomplish these objectives, a design process shown in Figure 2 was used by the researcher to develop an early prototype. Following the initiation of the design request by the FAA, a review of literature was completed.

Anthropometric Data

The FAA requested that the life vest fit 80 percent of the adult male and female U.S. population. Anthropometric data were obtained from two sources: Anthropometric Source Book Volume I (1978), and Human Dimension and Interior Space (1979). The data reported in each working source were taken from descriptive military and civilian populations and modified to estimate 1985 population dimensional projections. Physical dimensions for women were calculated using a 1968 Air Force Women's survey (McConville, 1978).

This researcher compiled anthropometric measurements for portions of the anatomy perceived as influential in the development or function of a prototype life vest. The data for the adult U.S. male and female population are reported in Table I. The data represented the population

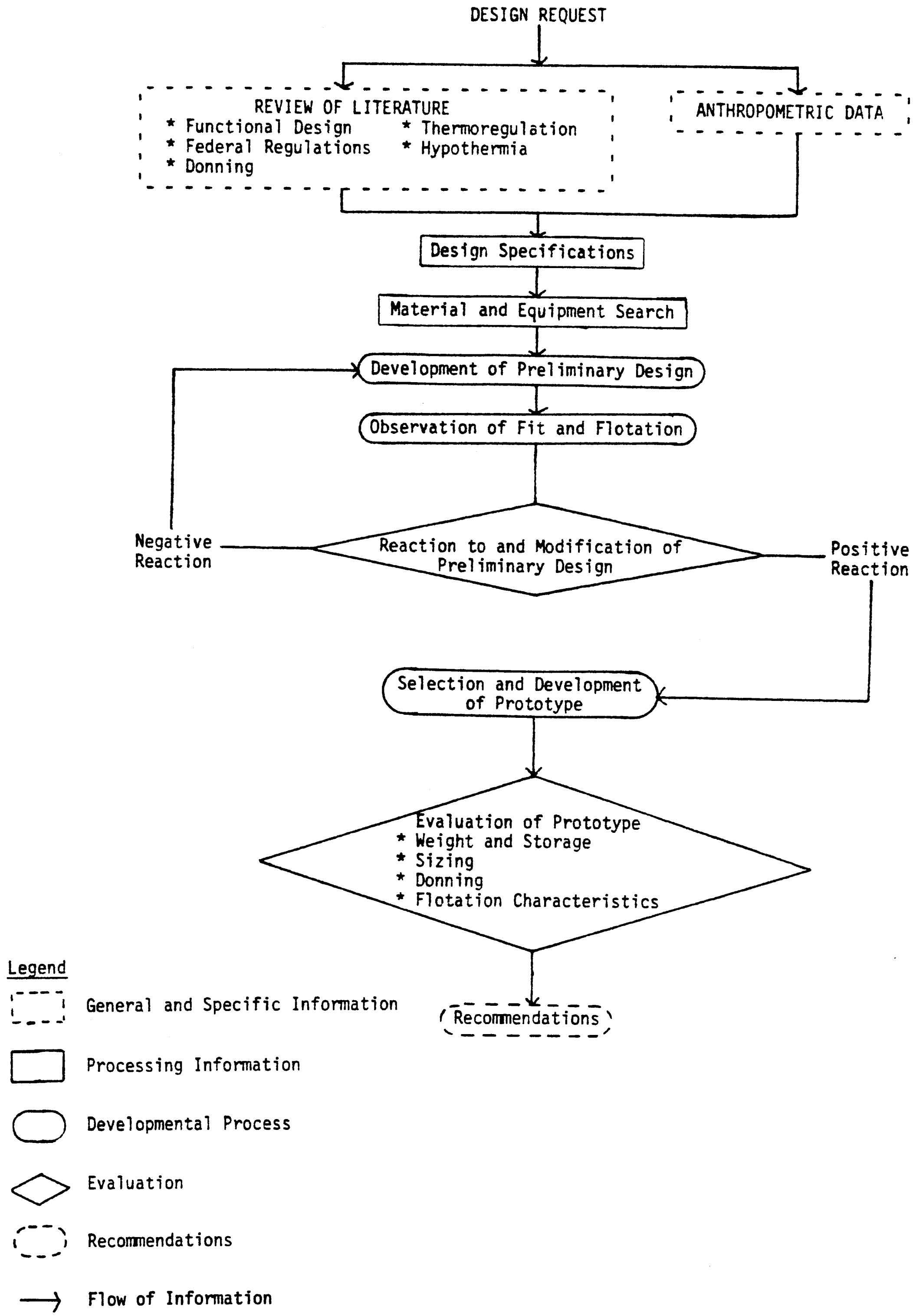


Figure 2. Knoepfli's Design Process for Development of Life Vest for the FAA

TABLE I

ANTHROPOMETRIC MEASUREMENTS FOR THE U.S. MALE AND FEMALE POPULATION

Portion of the Body being Measured	Figure and Reference Number **	Percentage of the Population	Male	Female	Maximum Measurement*	Minimum Measurement*	Difference in Measurements *
Head Circumference	3 - A	95	23.6 [a]	22.8 [a]	23.6	20.7	2.9
		5	21.8 [a]	20.7 [a]			
Face Breadth	3 - B	95	5.9 [a]	5.5 [a]	5.9	4.7	1.2
		5	5.3 [a]	4.7 [a]			
Neck Circumference	3 - C	95	16.5 [a]	14.7 [a]	16.5	12.3	4.2
		5	14.0 [a]	12.3 [a]			
Shoulder Width (Biocromial Breadth)	4 - D	95	17.3 [a]	15.3 [a]	17.3	13.1	4.2
		5	14.8 [a]	13.1 [a]			
Shoulder Circumference	4 - E	95	50.6 [a]	44.0 [a]	50.6	36.7	13.9
		5	42.9 [a]	36.7 [a]			

* Measurements are given in inches.
** Figure and reference number are given in Appendix A.

TABLE I (Continued)

Portion of the Body being Measured	Figure and Reference Number **	Percentage of the Population	Male	Female	Maximum Measurement*	Minimum Measurement*	Difference in Measurements *
Shoulder Length	4 - F	95	7.4 [a]	6.5 [a]	7.4	5.2	2.2
		5	5.8 [a]	5.2 [a]			
Shoulder Breadth (Bideltoid)	4 - G	95	20.8 [a]	18.4 [a]	20.8	15.2	5.6
		5	17.5 [a]	15.2 [a]			
Chest Circumference at Scye	4 - H	95	43.2 [a]	40.8 [a]	43.2	32.4	10.8
		5	35.1 [a]	32.4 [a]			
Bust/Chest Depth	5 - I	95	10.9 [a]	11.1 [a]	10.9	8.3	2.6
		5	8.5 [a]	8.3 [a]			
Backshoulder (Interscye)	6 - J	95	17.8 [a]	15.7 [a]	17.8	12.4	5.4
		5	12.8 [a]	12.4 [a]			
Chest Breadth	6 - K	95	14.4 [a]	12.7 [a]	14.4	10.0	4.4
		5	11.7 [a]	10.0 [a]			

* Measurements are given in inches.
** Figure and reference number are given in Appendix A.

TABLE I (Continued)

Portion of the Body being Measured	Figure and Reference Number **	Percentage of the Population	Male	Female	Maximum Measurement*	Minimum Measurement*	Difference in Measurements *
Waist Circumference	6 - L	95	39.6 [a]	31.7 [a]	39.6	23.4	16.2
		5	30.1 [a]	23.4 [a]			
Buttock Circumference	6 - M	95	42.9 [a]	42.0 [a]	42.9	33.9	9.0
		5	35.6 [a]	33.9 [a]			
Hip Breadth (Sitting)	3 - N	95	16.6 [a]	16.4 [a]	16.6	13.9	2.7
		5	13.5 [a]	13.9 [a]			
Waist Front Length	4 - O	95	17.4 [a]	14.6 [a]	17.4	12.0	5.4
		5	14.6 [a]	12.0 [a]			
Waist Back Length	6 - P	95	20.1 [a]	17.5 [a]	20.1	14.5	5.6
		5	17.0 [a]	14.5 [a]			
Verticle Trunk Circumference	5 - Q	95	71.2 [a]	66.5 [a]	71.2	57.2	14.0
		5	62.0 [a]	57.2 [a]			

* Measurements are given in inches.
** Figure and reference number are given in Appendix A.

TABLE I (Continued)

Portion of the Body being Measured	Figure and Reference Number **	Percentage of the Population	Male	Female	Maximum Measurement*	Minimum Measurement*	Difference in Measurements*
Midshoulder Height Sitting	3 - R	95	27.4 [a]	24.8 [a]	27.4	21.3	6.1
		5	23.9 [a]	21.3 [a]			
Biceps Circumference Relaxed	7 - S	95	13.8 [a]	12.2 [a]	13.8	9.0	4.8
		5	10.7 [a]	9.0 [a]			
Scye Circumference	7 - T	95	21.0 [a]	16.5 [a]	21.0	13.4	7.6
		5	17.4 [a]	13.4 [a]			
Sleeve Length	3 - U	95	38.3 [a]	33.5 [a]	38.3	29.2	9.1
		5	33.7 [a]	29.2 [a]			
Side Arm Reach	7 - V	95	39.0 [b]	38.0 [b]	39.0	27.0	12.0
		5	29.0 [b]	27.0 [b]			
Wrist Circumference	7 - W	95	7.6 [a]	6.4 [a]	7.6	5.4	2.2
		5	6.4 [a]	5.4 [a]			

* Measurements are given in inches.
** Figure and reference number are given in Appendix A.

TABLE I (Continued)

Portion of the Body being Measured	Figure and Reference Number **	Percentage of the Population	Male	Female	Maximum Measurement*	Minimum Measurement*	Difference in Measurements *
Height	4 - X	95	74.3 [a]	68.0 [a]	74.3	60.0	14.3
		5	66.2 [a]	60.0 [a]			
					Maximum Measurement in Pounds	Minimum Measurement in Pounds	Difference in Measurements
Weight		95	215.4 [a]	165.1 [a]	215.4	104.5	110.9
		5	143.7 [a]	104.5 [a]			

* Measurements are given in inches.
** Figure and reference number are given in Appendix A.

Sources: a. In staff of Anthropometric Research Project Webb Associates (Ed.), Anthropometric Source Book Volume I: Anthropometry for Designers. (NASA Reference Publication 1024), Yellow Springs, Ohio: Webb Associates, 1978.

b. Panero, J. and Zelnick, M. Human Dimension and Interior Space. New York: Watson-Guptill, 1979.

segment contained between the fifth and ninety-fifth percentiles. The tenth and nintieth percentiles were not used because data from the literature were most often reported as the fifth and ninety-fifth percentiles. The data were used to calculate the difference between the maximum and minimum body measurements. Illustrations were completed for each specified portion of the body to enable quick visual reference of anatomical differences. The illustrations are reported in Appendix A, Figures three through seven. The anthropometric data were used to draft slopers and make pattern alterations.

Design Specifications

Eight regions of the anatomy were identified: 1) head and neck, 2) torso length, 3) shoulders, 4) armscye, 5) chest, 6) waist, 7) groin, and 8) hips. For each body region, possible problems regarding sizing, donning, and thermal protection were outlined and alternative solutions were proposed. For example, at the head and neck, one donning problem identified involved closures for the neck opening. It was concluded that closures should be easy to manipulate, and should stay secure and in place once attached. Alternative solutions to this design problem included snaps, velcro, ties, hooks, or an overlapping flap.

The identification of various design problems enabled the development of the following design specifications.

1. The life vest must accommodate the adult U.S. male and female population whose anthropometric configuration lies between the fifth and ninety-fifth percentile. The 95th percentile is represented by the following anthropometric measurements: neck circumference 16.5"; shoulder length 7.4"; shoulder width 17.3"; scye circumference 21";

chest circumference 43.2"; waist circumference 39.6"; buttock circumference 42.9"; vertical trunk circumference 71.2"; waist front 17.4"; and waist back 20.1". The fifth percentile is represented by the following anthropometric measurements: neck circumference 12.3"; shoulder length 5.2"; shoulder width 13.1; scye circumference 13.4; chest circumference 32.4; waist circumference 23.4"; buttock circumference 33.9"; vertical circumference 57.2"; waist front 12"; and waist back 14.5".

2. The life vest should not inhibit breathing, blood circulation, or movement.

3. The life vest should require simple comprehension thereby decreasing donning time.

4. The closures should be limited in number, and easy to manipulate. The manner in which the closure functions should be readily understood.

5. An individual must be able to don the life vest while seated.

6. The vest should provide flotation which will support the head and neck and maintain the body in a face-up position thus preventing water from channeling into the breathing passage.

7. The life vest should slide on over existing clothing with little abrasion.

8. The life vest should insulate critical areas of the body to minimize heat loss.

9. The vest should inhibit the water flow into and between the body and life vest.

10. A minimum number of seams should be used to limit water seepage.

11. Light weight materials with maximum insulation values should be used to construct the life vest thus keeping weight and size to a minimum.

Material and Equipment Search

A material and equipment review was conducted by reviewing the literature and completing a market search which identified materials and design ideas that achieved prototype characteristics described in the design specifications. The literature review included outdoor sporting goods magazines and books dealing with cold water survival. The market search required visiting various retail establishments and viewing boating, fishing, and snow skiing equipment.

Sporting Goods Equipment

A market search revealed desirable and undesirable design features of two types of sporting goods equipment; fishing vests and boating equipment. Desirable design features of the fishing vests included: front opening, nylon zipper, v-neckline, simple donning, method for providing buoyancy, versatility of fabric, and the support provided for the head and neck. Desirable design features of boating equipment included: laced side seams for adjusting size, buckles and belts for adjusting fit, simple design, easy donning, and method for providing buoyancy. Undesirable features of boating and fishing life vests included: predetermined sizing, short waist length of garment front and back, and large arm openings. Undesirable features of boating equipment included: excessive bulk and inadequate support for the head and neck.

Various equipment styles and forms of hardware were identified as design alternatives using sporting goods equipment.

Protection and Survival Equipment

Other design alternatives were inspired by a review of protection and survival equipment. Protection and survival equipment is designed to increase survival time and provide protection against adverse conditions. U.S. Air Force flight crews use a gas inflated device mounted on the waistcoat (Lee, 1980). The device is inflated by the victim after entering the water. Once inflated the air bladder expands into an innertube around the victim's waist. A positive attribute of this device was that it was donned prior to take off, alleviating the need to don the device during a crisis situation. Characteristics not appropriate to this project included: no support for the head and neck and the inability to right an unconscious victim. Various forms of protection and survival equipment exist, each possessing features desirable for an intended purpose.

Divers use the dry suit as a piece of equipment which increases survival time and provides protection during submersion. This device requires adequate time and space to don. When donned properly no water enters the suit. Water destroys the dead air space between the body and suit which contributes to the insulating capabilities of the dry suit (Pozos, 1982). A layer of closed cell foam is used to provide thermal protection and buoyancy (Collins, 1983). The dry suit is available in half- and full-body lengths. The half-body suit is equipped with a flap to cover the groin and protect it against exposure. The thermal protection provided by this device is a positive design feature but is counter balanced by the fact that there is not adequate time or space to don such a garment in an aircraft, and the device is not capable of providing adequate buoyancy.

Thermal protection, not buoyancy is often the major concern of survival and protection equipment. Lee (1980) describes a one piece waterproof garment called a survival suit which covers the feet, legs, trunk, arms, and head, however, the hands and face are left exposed. The survival suit is donned through a wide neck opening. Water seepage is kept to a minimum by using a drawstring and rubber toggle at the neck opening and rubber seals at the wrist. To provide buoyancy a life jacket must be worn with the survival suit. Another form of the suit has slightly different characteristics. A polymer coated synthetic textile is used to construct the garment (Lee, 1980). The suit is interlined with closed cell foam and lined with foil to reflect heat. A watertight zipper extends from the neck to the crotch to facilitate donning. Positive features of the survival suit as related to this project are thermal protection, sealed garment openings, and full-length zipper. Negative attributes include size, weight, method for providing buoyancy, and effort required to don.

Another device, the exposure suit, was designed to be used on open rafts or boats providing thermal protection against the cold (Lee, 1980). The garment is constructed of two layers of light weight water proof fabric. The two layers of fabric function as an air bladder. A gas cylinder or a device for oral inflation is used to inflate the suit. The dead air space functions as the insulation for the exposure suit. The garment is held together every few inches by spacer diaphragms creating a quilted appearance (Lee, 1980). The exposure suit was not designed to be used during immersion.

A device designed for immersion is the immersion suit. This device is available as a full-length one piece garment or as two separate pieces, described by Lee (1980) as blouse and trousers. The one piece suit is constructed of "...ventile water-resistant closely-woven cotton fabric" (Lee, 1980, p. 265). Fabrics lighter in weight but with similar characteristics are also used to construct this device. Donning of the full-length immersion suit is facilitated by two sliding fastners. The garment is fitted at the neck, wrist, and waist and is provided with a detachable hood. The two piece immersion suit is identical to the full-length suit with one exception, it is sealed at the waist by rolling the blouse and trousers together forming a water tight seal (Lee, 1980). The immersion suit offers three design possibilities: a hood, sealed openings, and waterproof fabric. Negative qualities as related to this project include: method of sizing, the actual donning, and the size and weight of the device.

The wet suit is a device designed to slow the onset of hypothermia during immersion. It is available in various styles: a one-piece suit with zipper entry; a one-piece suit which is donned by stepping into the device and securing it with velcro closures; and the use of separate or individual pieces (Lee, 1980). The device is constructed of "...expanded neoprene with smooth exterior finish and nylon towelling lining" (Lee, 1980, p. 266). The closed cell foam acts as a barrier between the water that enters and the exterior water. The thicker the foam, the greater the thermal protection and buoyancy provided. This device fits snugly, allowing little water seepage. Lee (1980) said water seepage is minimized by using mauser stitches, which are used to construct wet suits used in surface activity, and cup stitches which are used to construct wet suits used in under water work. Positive attributes of this suit are the zipper, velcro, fabric, stitching, and thermal protection. Less desirable features of the wet suit as related to the prototype included: inadequate buoyancy, complicated donning procedures, weight, and sizing.

A device called the casualty bag was designed for victims of hypothermia and is used by rescue teams to warm a victim. The device is constructed in one of two fabrics -- strentex or aluminized polyester film which reflects radiant heat (Lee, 1980). Advantages of the device are that it provides protection against water and wind by insulating the body (Collins, 1983). Lee (1980) identifies difficult donning as a disadvantage of the casualty bag.

Hunting, Fishing, and Skiing Clothing

Outdoor clothing for hunting, fishing, and skiing provided another source for design ideas. The researcher limited the material search to coats and parkas. Design features, such as closures, seams, garment openings, methods of sizing, thermal protection, fabrics, and insulations were noted. Fabrics and insulation materials are discussed in greater detail later in the chapter. Design features for prototypes included:

1. Hardware used as closures were velcro, large toothed nylon zipper, and large snaps.

2. A minimum number of seams in the garment front, back, and shoulder decreased the amount of water seepage.

3. Seams were sealed by a sealant or heat to decrease water seepage through seams.

4. Bodice openings at the neck, arms, wrists, waist, and hip were sealed by velcro, ribbing, drawstrings, and elastic.

5. Sizing methods identified included predetermined sizes, a belt or drawstring run through exterior carriers, or a belt or drawstring run through a casing. The belts and drawstrings used to adjust fit also drew the garment toward the body trapping body heat.

6. Body heat was maintained and thermal protection provided using a hood, high standing collar, storm skirt, and storm flap over the zipper.

Fabric and Insulation

Outer fabric, insulation, and structural design features contribute to thermal protection. The fabrics and insulative materials used in outdoor clothing offered possible design alternatives for the prototype. Fabrics possessing thermal qualities of low water absorbency and waterproofing were discussed first.

Three textile fibers used to construct outdoor clothing are nylon, polyester, and wool. All three fibers are strong and maintain good resistance to abrasion (Eugenis, 1984). Polyester and nylon, two light weight synthetic fibers which maintain great strength when wet, have low moisture absorbancy, resist alkali, mildew, and insects (Eugenis, 1984). Wool, unlike these two fibers, is heavy, has a high moisture absorbancy, and requires treatment against insects.

Many of the fabrics used in outdoor clothing are chemically treated to provide waterproof qualities. There are a number of companies who produce laminants or laminated fabrics which are waterproof. Laminants are chemical compounds applied to fabrics or to fibers prior to weaving (Woodward, 1984).

Woodward (1984) describes three laminants applied to fabric. Entrant®, a laminant used in Japan, is thin and leaves the fabric with a supple feel. The coating produces millions of perforated pores on the fabric which allows moisture to pass out, not allowing moisture to penetrate from the outside. Two other laminants, Matrex® and Imtrex®, have been produced by the Polypore Division of International Microporous Technology Incorporated. These laminants create soft waterproof fabrics that do not crinkle. Matrex, a thick laminant, does not allow body moisture to pass out while Imtrex, a thinner laminant, does allow body moisture to pass through the fabric. All three products are applied to woven fabric.

Gamex® and Savina® are laminants applied to fibers before they are woven into fabrics. Gamex is applied to polyester fibers which are converted into yarns and then tightly woven. Savina, similar to Gamex, is applied to high filament yarns and is also tightly woven. The fabrics are run through a finishing bath (Woodward, 1984), expanding the yarns and shrinking the fabric. This process produces a microporous fabric that is lightweight, water repellent, and breathable.

W.L. Gore and Associates have produced a laminant called Gor-Tex® that is recommended by many outdoor recreation magazines. "A biochemical membrane that is both oleophobic (impervious to oil) and hydrophobic (impervious to water)..." (Woodward, 1984, p. 44) is applied between two fabrics producing a waterproof, yet breathable fabric. This microporous material provides billions of pores to the inch and is only .001 inches thick and weighs one half ounce to the square yard. The fabric is composed of an inner lightweight nylon and an exterior fabric of the manufacturer's choice according to "Outdoor fabrics that keep out water, let vapor throught" (1980). Garments constructed from Gor-Tex require that seams be sealed by heat or a sealant that retains the waterproof quality of the fabric.

Peter Storm has produced a product called "No Sweat"® which allows body moisture to pass through the fabric away from the body while remaining impervious to water entering from the outside. The fabric is 100 percent waterproof and stretches with an individual's movement. (This information was obtained from various advertisements; no other information could be obtained from the manufacturer.)

Laminated fabrics are used year round in outdoor sportswear. Garments for winter recreation are typically interlined with an insulative material. The insulation traps and maintains body heat without creating unnecessary bulk or weight, while providing the water proof and breatheable qualities of laminated fabric. Products manufactured by Reliance, DuPont, Kodak, and 3M have been briefly discussed in the following text.

Reliance Products have developed Celanese Fortrel Polar Guard® and Polar Fleece®. These polyester fiberfills are constructed of continuous filaments that do not require quilting. Polar guard is compressible, resilient, and fast drying (McKeown, 1982).

DuPont produces products called Dacron Hollofil 808®, Dacron Hollofil II®, Quallofil®, and Sontique®. Each is a thin insulation material constructed of staple polyester fibers. Good loft, light weight, low moisture absorption, softness, and compactibility are a few of the qualities provided by these products. The Hollofil fiber is like a tube with a hollow center. DuPont's research showed that a hollow-core fiber created more loft per unit of weight improving thermal efficiency (Eugenis, 1984). Quallofil, a lighter weight fiber, is constructed in a similar manner. Four hollow holes are used to increase dead air space instead of one hole (Eugenis, 1984). This fiber does not absorb water, nor lose loft or insulative ability when wet (Eugenis, 1984). Sontique is a micro thin fiber used to design insulated garments with a thin silhouette (McKeown, 1982).

Eastman Chemical Products, a Division of Kodak, produces three different insulation materials. McKeown (1982) describes KodOfill® as a tubular filament crimped for extra loft. KodOsoff®, a variation of KodOfill, provides additional softness, loft, and resiliency. KodOlite®, a microfine fiber produced by Eastman Chemicals, was developed to provide a light and trim insulating fabric.

An insulation material called "Thinsulate"® has been developed by 3M. "Thinsulate weighs anywhere from 25 percent to 52 percent less than polyester fiberfills of given warmth" (Netherby, 1979, p. 118). Reports issued by 3M indicate that their insulation provides approximately two times the thermal insulation of competitors including polyester fiberfill, pile, and wool (Thinsulate Technical Bulletin, n.d.). This olefin compound of polypropylene allows for less bulk and for the retention of heat while being compressed (McKeown, 1982) and continues to insulate effectively while wet, only losing approximately 20 percent of the insulation's effectiveness (Miller, 1979).

Thinsulate is produced in various weights and thicknesses for numerous purposes. Three types of thinsulate are "M," "B," and "C." Type "M" is used in products requiring high density and is constructed of 100 percent polyolefin, a "Man-made fiber made from polymerized olefin such as polyethylene or polypropylene" (Wingate, 1979, p.471). This batting resists crushing and is used in items such as boots and gloves. One hundred percent olefin microfibers are used to construct Type "B." Thinsulate Type "B" is used in diving suits and footwear because it retains 1 percent of its weight in water when damp, is light weight and thin, as well as compression resistant.

Type "C" thinsulate is used in apparel and housewares. This nonwoven batting provides exceptional thermal qualities and is composed of 65 percent olefin and 35 percent polyester. The batting is low density, lightweight, provides loft, good drape, softness, and compressability (Thinsulate Technical Bulletin, n.d.). The loft and thermal performance of Type "C" are not hindered by water absorption or compression due to storage. Less than 1 percent of the batting's weight in water is retained (Thinsulate Technical Bulletin, n.d.) and the compressability has passed military specifications for loft recovery (Thinsulate Thermal Insulation, n.d.). Greater than 90 percent of the loft is recovered under the specified tests. Thinsulate should not be subjected to temperatures above 100° C (212° F) since at 150° C (302° F) the batting begins to melt. Thinsulate products provide qualities desired for a prototype life vest.

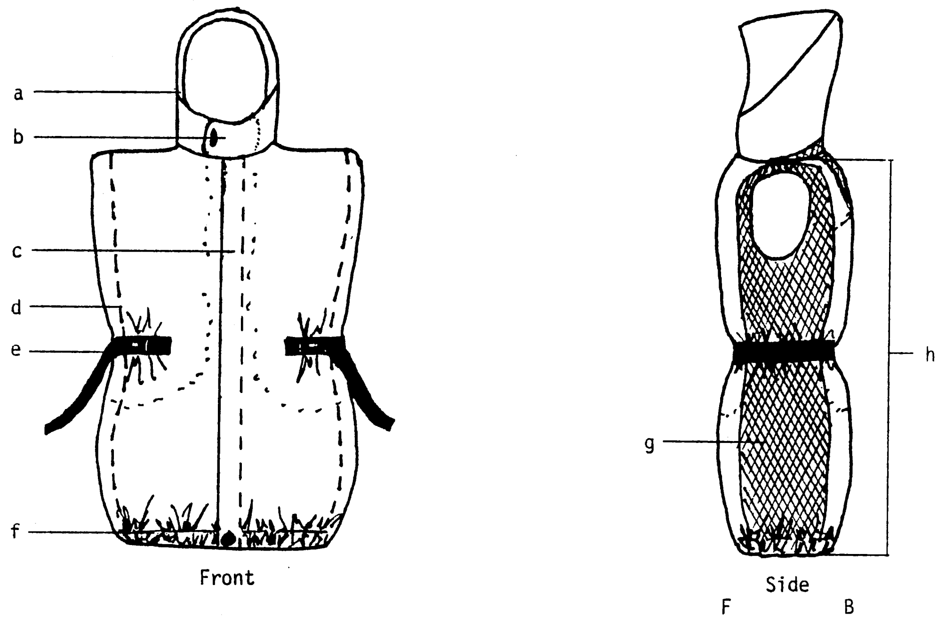
Down was not viewed as a possible alternative for this project. Unlike synthetics, down loses loft and insulative qualities when wet (McKeown, 1982).

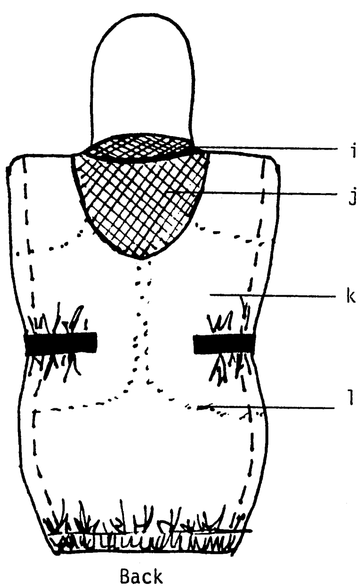
Kaufman, Bothe, and Meyer (1982) completed a study to determine the thermal insulating capabilities of four materials used in outdoor clothing; goose down, wool, polyester, and polyolefin. All samples were enclosed in a nylon shell and tested under dry conditions. The "...results show no superiority of any synthetic material over the natural fibers as thermal insulators, although down has a marked advantage in weight per unit loft (thickness)" (Kaufman, 1982, p. 690). No significant differences in thermal insulation existed during compression at reductions of 52 percent of the control value. Factors such as weight, drapability, durability, and cost will have to be considered when selecting an insulation, not a synthetic fiber versus a natural fiber.

The material and equipment review offered a number of design alternatives for the development of a prototype life vest for the FAA. The information was used simultaneously with the design specifications to develop preliminary designs. Materials and design features were selected carefully giving each design specification due consideration.

Development of Preliminary Design Styles A, B, and C

Three preliminary designs were developed and labeled Styles A, B, and C. Each style possessed features which accomplished the objectives of the project and fulfilled design specifications. Style A, as shown in Figure 8, provided a hood insulated with Thinsulate 200 (Feature a) to reduce heat loss at the head. A stretch band at the base of the hood (Feature i), located between the hood and back neckline of the bodice, was provided as a means for increasing the back hood length for the





Key to Figure	Design Features
a	Hood - lined with Thinsulate 200
b	Hood Closure
c	Zipper and Storm Flap
d	Pleat - extending the trunk length.
e	Belt
f	Elastic Cinch
g	Side Stretch Panel
h	Extended Bodice Front and Back
i	Stretch Band at the base of the hood.
j	Shoulder Back Stretch Panel
k	Closed Cell Foam
l	Quilting
m	Lining (not visible)

Figure 8. Style A

upper 80 percent of the population. A shoulder back stretch panel (Feature j) was provided for increasing the shoulder back width. The hood was closed at the center front by an overlapping flap (Feature b). This feature was provided to decrease the likelihood of water channeling directly into the face and mouth and was accomplished by including a small piece of closed cell foam within the flap.

The garment front and back length (Feature h) were extended below the hip to provide protection against heat loss at the groin for the ninety-fifth percentile as well as providing additional thermal protection for the smaller body configuration. Two pleats (Feature d) extended the trunk length on the front and back and were sewn down at the shoulder seam. The remainder of the pleat was left free for expansion. A side panel (Feature g) made of two way stretch fabric, extended from the shoulder to the lower edge. The panel was attached to the garment underneath the front and back pleats. The panel and pleats were designed to provide extra expansion around the girth. Elastic, sized for the fifth percentile was run through the casing (feature f) to adjust and maintain proper fit around the hips. A belt (feature e) attached at the waist on the outside of the life vest was used to hold the pleats in place and to cinch the life vest close to the body. The belt drew the bodice front and back sides closer together on the smaller framed body exposing less of the side stretch panel, thus increasing thermal protection for individuals in the fifth percentile.

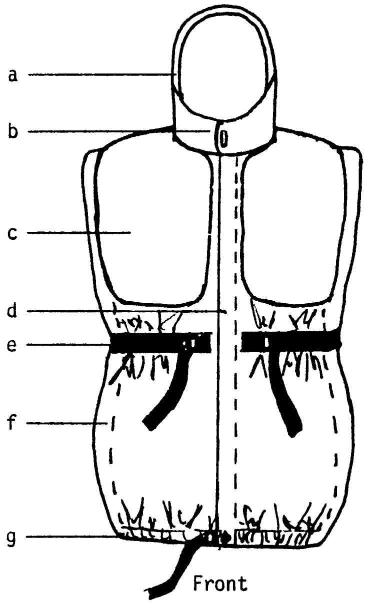
The life vest was secured with a full-length zipper (Feature c). The zipper was used to provide quick and accurate donning. A one and one-half inch storm flap extended over the center front zipper on the exterior of the garment to decrease water flow through the zipper. A snap was used to secure the center front opening at the hem.

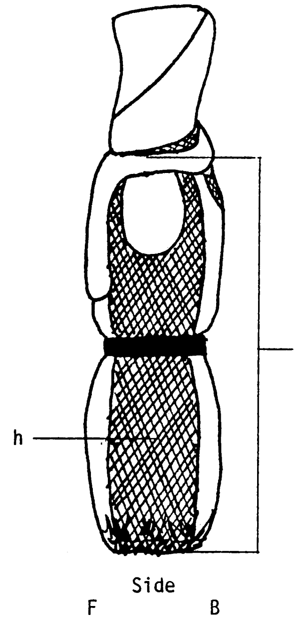
A light weight uncoated ripstop nylon provided the shell of the preliminary prototype Style A. Nylon was selected for its qualities of water resistance, low absorbancy, high abrasion, and light weight. Manufacturer's specifications report the fabric weight at 1.9 ounces per yard. Thermal protection and buoyancy were provided by closed cell foam (Feature k). A mesh fabric (Feature m) was used to line and hold the foam pieces in place (Feature 1).

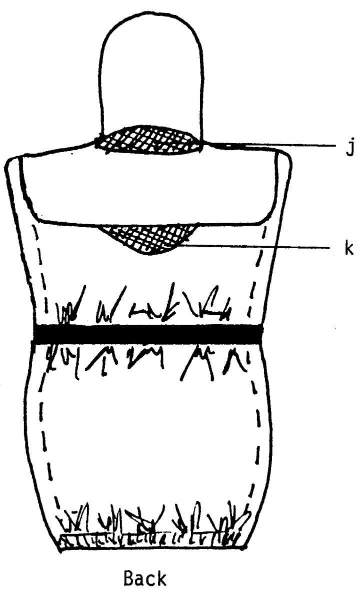
Style B, shown in Figure 9, was similar to Style A with the following exceptions. New features incorporated into Style B were labeled c, e, f, g, 1, and m. Two major differences existed in these styles; method of flotation and insulative material.

An air bladder (Feature c) attached to the outside of the life vest at the neckline provided buoyancy for Style B. The bladder was not sewn into the lining for two reasons: 1) it would have increased the dead air space between the prototype's shell and the insulative material allowing a greater area in which water would accumulate and 2) adequate support would not have been provided for the face and neck with the bladder sewn into the lining. The bladder had to be able to inflate next to the face and neck to provide support.

The torso front, back, and hood were lined with Thinsulate 200 (Feature 1) to increase thermal protection during immersion. The insulation was included in the pleats extending the front length and back (Feature f). None of the areas featuring stretch fabric were insulated allowing maximum expansion of the fabric. A light weight polyester fabric (Feature m) lined the life vest and was selected for







Key to Figure	Design Features
a	Hood - lined with Thinsulate 200
b	Hood Closure
c	Air Bladder
d	Zipper and Storm Flap
e	Belt
f	Pleat - extending the trunk length.
g	Cinch, Latch, and D-Ring
h	Side Stretch Panel
i	Extended Bodice Front and Back
j	Stretch Band at the base of the hood.
k	Shoulder Back Stretch Panel
l	Insulation - Thinsulate 200 (not visible)
m	Lining (not visible)

Figure 9. Style B

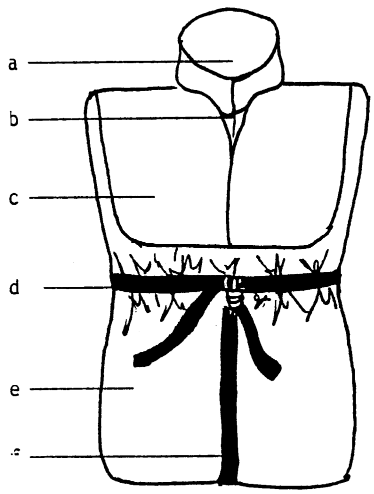
its characteristics of abrasion resistance, lightweight and low absorbency.

A belt (Feature e) was attached at the waist on the outside of the life vest. The belt encircled the life vest and was attached at the center back and on either side of the zipper at the center front. The belt was adjusted by pulling the belt ends through self-locking buckles located on each side of the zipper. Belt ends and buckles were positioned to increase accessibility and provide simple adjustment.

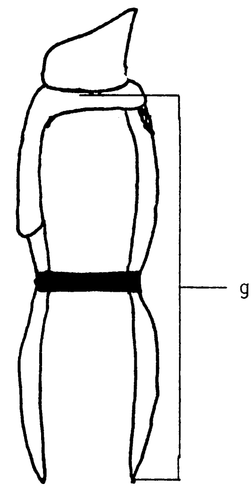
Webbing was applied to a casing at the hem (Feature g) for adjusting fit and holding the life vest in place at the hipline. A single ring was attached on the left front for snapping in place the latch attached to the right side. The webbing was adjusted by pulling the belt through D-rings attached at the right center front hem.

Style C, as shown in Figure 10, was designed to be donned over the head, eliminating armholes and reducing excess bulk and weight. Bodice front and back were designed as two separate free hanging panels (Feature e) and insulated with Thinsulate 200 to provide thermal protection for the body trunk. Flaps were held in place and secured by means of a belt (Feature d) and a groin strap (Feature f). The belt was secured at the center front and held in place at the center back by a belt carrier. The carrier was formed by attaching the groin strap at the center back waistline. The groin strap was brought up between the legs, attached and adjusted at the center front waist using D-rings. D-rings were also used to secure the belt at the waist.

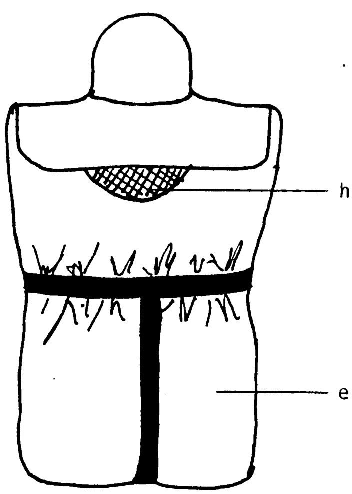
Increased thermal protection for the head and neck was provided by a high standing collar (Feature a) lined with Thinsulate 200. The collar was shaped to provide height at the back of the head. This



Front



Side
F B



Back

Key to Figure	Design Features
a	High Standing Collar
b	Center Front Flap
c	Air Bladder
d	Belt
e	Bodice Front and Back Panel
f	Groin Strap
g	Extended Bodice Front and Back
h	Shoulder Stretch Panel.
i	Lining (not visible)
j	Insulation - Thinsulate 200 (not visible)

Figure 10. Style C

design feature was less likely to inhibit hearing and sight than the hooded prototypes, Styles A and B, while providing minimal thermal protection. At the center front junction of the collar and neckline an adequate neck opening and a flap extension (Feature b) were provided to allow simple donning over the head. The flap was applied to reduce the influx of water at the neckline. No closure was necessary because the neck opening was held secure by an air bladder attached at the neckline. The air bladder (Feature c) was applied to Style C for the same reasons stated for Style B. Other design features such as g, h, i, and j were also repeated in Style C, but for the reasons stated for Style A.

Sloper, Pattern, and Preliminary Prototype Construction for Styles A, B, and C

A sloper for garment front and back was drafted using methods described by Handford (1974) in _Professional Pattern Making for Designers of Women's Wear_. Patterns for Styles A, B, and C were constructed from this sloper. Table II gives the measurements used to draft the sloper and patterns. Measurements were derived by dividing the difference of the maximum and minimum body measurements (reported in Table I) by two and adding the quotient to the minimum body measurement. These measurements were to be representative of the fiftieth percentile.

The pattern for Styles A, B, and C were constructed from the sloper, each style varied only in materials and hardware. Preliminary prototypes A, B, and C were constructed as full scale functional prototypes. Similar methods and procedures were used for constructing each prototype. It is important to note that the air bladders of Styles B and C were approved flotation devices supplied by the FAA. Air

TABLE II

MEASUREMENTS USED TO CONSTRUCT SLOPER AND PATTERNS FOR STYLES A, B, C, D, AND E

Portion of Body	Medium(a) Anthropometric Measurements(b)	Final Pattern Measurements
Head Circumference	22.15	24
Neck Circumference	17.95	14
Shoulder Width	18.00	16
Shoulder Length	6.30	5
Chest Circumference	37.80	36
Back Shoulder	15.10	
Chest Breadth	12.20	
Waist Circumference	31.50	36
Buttock Circumference	38.40	36
Waist Front Length	16.05	16
Waist Back Length	17.30	16
Vertical Circumference	64.20	68
Scye Circumference	17.20	18
Head-neck Length		13.5

Note: a) Measurements were derived by dividing the difference of the maximum and minimum body measurements (reported in Table I) by two and adding the quotient to the minimum body measurement.

b) Measurements are given in inches.

bladder construction was not within the scope of this study. Existing equipment was modified to fit the researcher's designs.

The air bladder for Style B was modified by removing all belts and splitting the device up the center front. The bladder was positioned around the hood at the neckline. The device was then securely attached at the center back neckline, on both sides of the center front neckline and at the shoulder seams of the neck edge. Small pieces of velcro were attached at the base of the bladder at the center front to hold the device secure during the donning process. The bladder for Style C was attached in the same manner with two exceptions: 1) the bladder was not split up the center front and 2) no velcro was used to secure the bladder edges at the center front. Before further prototype development could be completed it was necessary to observe each completed prototype donned and immersed in water.

Observation of Fit and Flotation for Styles A, B, and C

Preliminary evaluations of Styles A, B, and C were completed at the Protection and Survival Laboratory in Oklahoma City, Oklahoma. The purposes of the preliminary evaluations were to observe each prototype during immersion and to receive the FAA's reactions to preliminary designs. The observation process involved three phases: 1) observations and reactions prior to entering the survival tank, 2) observations and reactions during immersion, and 3) observations and reactions upon exiting the tank. Each design was donned by Gordon Funkhouser, a research physiologist at the laboratory. Funkhouser's anthropometric configuration was representative of the fiftieth percentile. His anthropometric measurements are identified as subject number six as recorded in Table V, Appendix B. Observations and reactions to fit, buoyancy, comfort, donning, and perceived thermal protection were based on the researcher's perceptions and Funkhouser's experience during each phase of the observation process.

The first phase of the observation process required administering oral donning instructions for each preliminary prototype. Based on instructions, Funkhouser donned each prototype in succession while standing. The researcher assisted in the donning process when necessary. Donning ease, fit and comfort were noted and recorded.

In the second phase of the preliminary observation, Funkhouser eased into the survival tank wearing the preliminary prototype. While gently treading water, four turns were made allowing the researcher a front, side, and back view of each design. The researcher was interested in buoyancy, support for the head and neck, comfort, fit, and any unforseen characteristics displayed by the prototype during immersion.

The final phase of the observations process occurred as Funkhouser exited the survival tank. He was asked not to adjust the prototype's position as he exited the pool enabling the researcher to note any displacement of the prototype caused by immersion.

Observations and reactions were noted for each phase and have been described in the following text. Prototype Style A was observed to be excessively bulky, inhibiting quick and accurate donning. The prototype provided adequate sizing capabilities, was comfortable and did not bind or restrict Funkhouser in any way. The hood did seem to inhibit hearing and vision slightly.

Once in the water, the adjacent pieces of foam began bending and bowing (Figure 11). The displacement of the foam caused the prototype to ride-up on the body, thus further distorting the prototype's fit. The foam placed in the hood flap slipped out of place and did not keep Funkhouser's face from becoming submerged. The foam pushed up around the face, caused chafing, and inhibited Funkhouser's capability to hear what was being said from pool side (Figure 12).

Funkhouser simulated an unconscious posture while immersed in order to test the capability of the prototype for righting an unconscious victim. The prototype did not allow the body to roll back over into a face-up position. It was necessary to reverse the process due to this factor. Funkhouser positioned himself on his back in a face-up position and after a short period of time the prototype began rolling his body back over into a face-down position.

Upon exiting the water, the distortions noted during immersion became more apparent. The prototype was no longer positioned as it had been donned. The hem was positioned at the waistline, the foam was pushed up around the face, and the front closure flap at the hood neckline was out of place. A gap of approximately four inches existed between the shoulder and the shoulder seam of the prototype.

The observation process was repeated for preliminary prototype Style B. While trying to don the prototype, Funkhouser had difficulty putting his hand through the armscye. He continually punched his hand into the side stretch panel. Once donned, adjusting and securing the prototype became confusing. The velcro used to hold the air bladder in position along the center front was inadequate. The bladder became loose and got caught in the zipper. The two belt ends at the waist

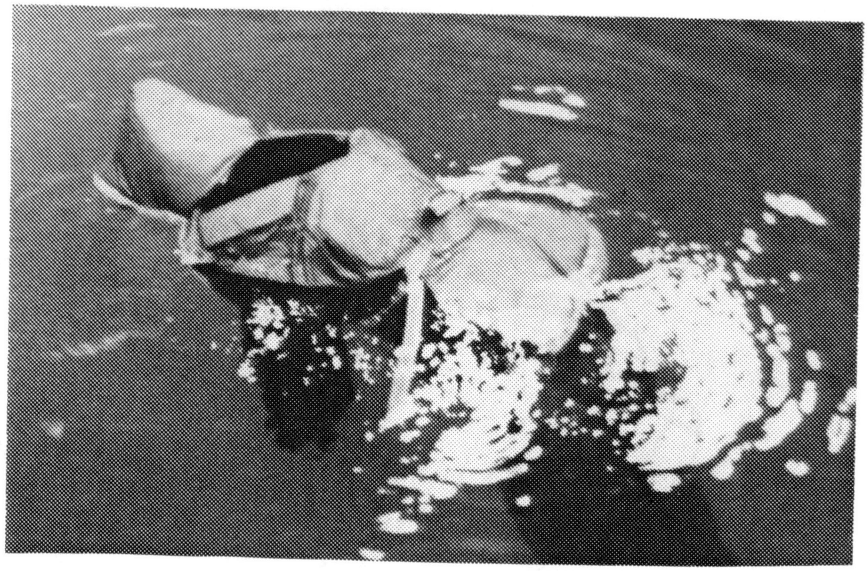


Figure 11. The Bowing of Closed Cell Foam and the Riding Up of Style A

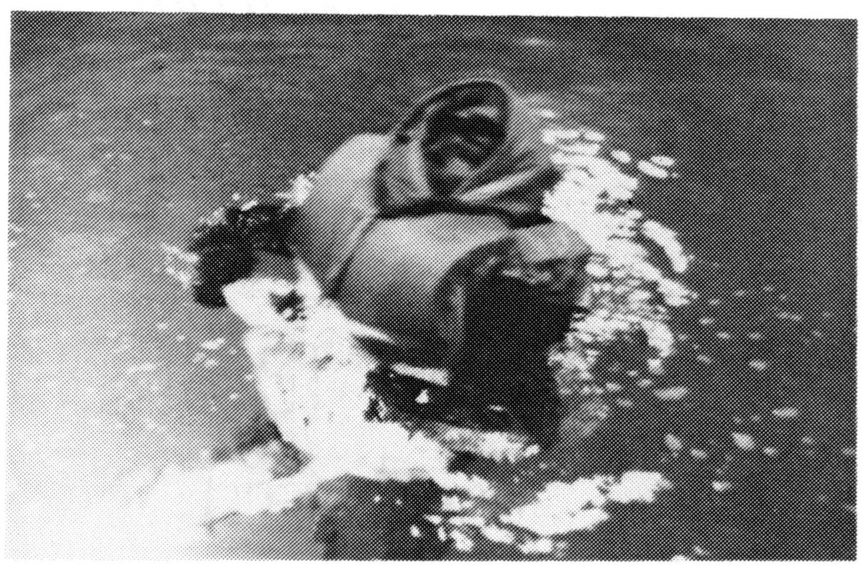


Figure 12. The Foam Pushed Up Around the Face

became tangled and also caught in the zipper. The zipper and zipper tab were too small for Funkhouser to grasp and manipulate easily. Once the garment was donned and properly adjusted, Funkhouser entered the water.

Prototype Style B had no problem supporting Funkhouser's body. Simulating an unconscious state the prototype was able to roll the subject to an up-right position. During the movement required to simulate unconsciousness, the neckline of the prototype became uncomfortably tight. The pressure exerted by the water and the movement of the subject caused the bladder to break loose at the front neckline. The snug fit of the air bladder around the neck and face and the hood covering the ears impaired Funkhouser's hearing. During active movement in the water the prototype did maintain its position on the body as illustrated in Figure 13.

The third prototype donned and immersed was Style C. The prototype was simple to don but difficult and confusing to secure and adjust. The D-rings used to attach the straps took too much time to thread the webbing through before the prototype could be cinched tight against the body. The crotch strap was inconvenient to attach.

Prototype Style C provided adequate buoyancy, supporting the head and neck above the water surface. During simulated unconsciousness, the prototype rolled Funkhouser's body back into a face-up position with ease. The sides of the prototype at the hem folded up during immersion (Figure 14) decreasing thermal protection for the lower body. The high collar did not inhibit Funkhouser's ability to hear during immersion and provided protection against abrasion caused by the air bladder next to the face and neck.

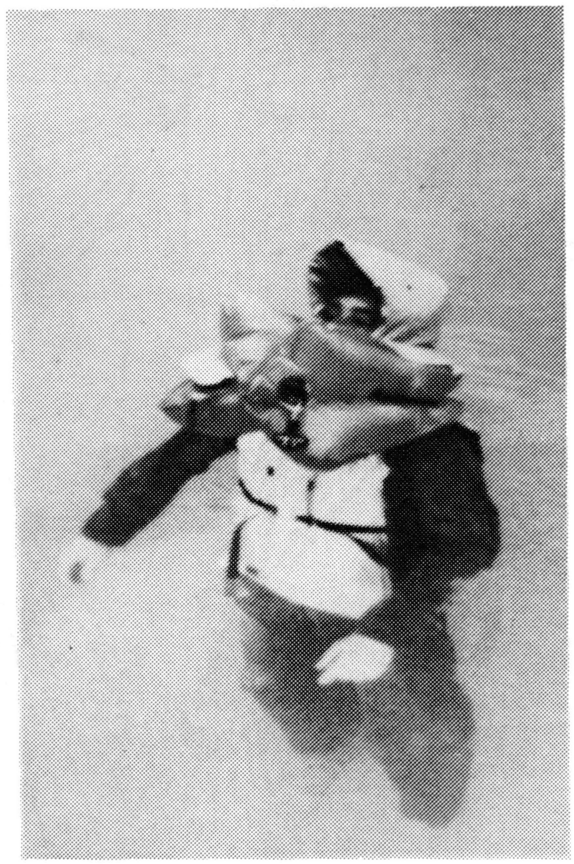


Figure 13. Style B did Not Ride Up

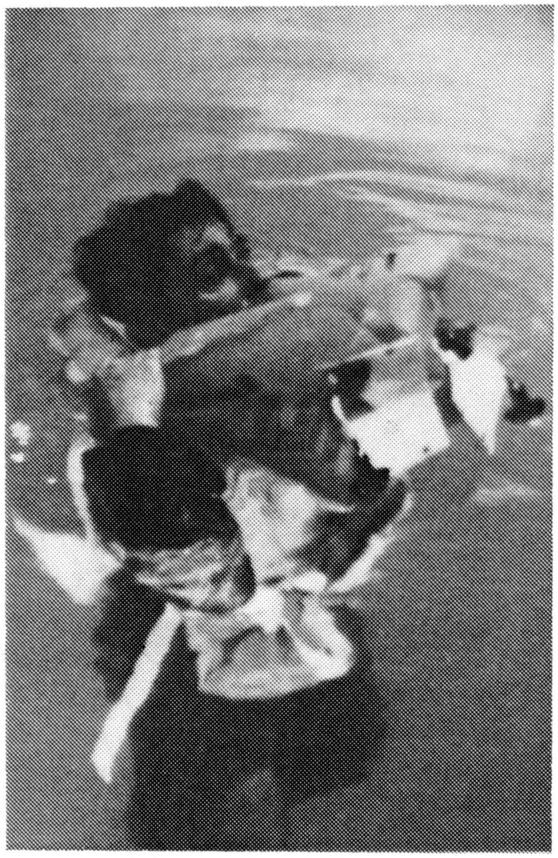


Figure 14. The Sides of Style C Folded Up

Reactions to and Modifications of Preliminary Prototype Styles A, B, and C

Examination and preliminary testing of prototype Styles A, B, and C allowed the researcher an opportunity to obtain the FAA's reaction to each preliminary design. The reactions were used to modify the existing designs and inspire new designs.

Preliminary testing showed Style A to be excessively bulky to don and store on board an aircraft (Higgins, Funkhouser, and Saldivar, 1983). The prototype weighed 913 grams without CO2 cylinders and a rescue light and maintained the following dimensions when folded for storage: length 14.5 inches, width 11 inches, and height 8 inches. The closed cell foam caused the prototype to ride-up and become distorted while submerged. The prototype was not capable of turning a subject face-up or maintaining the subject in a face-up position during immersion. Due to these factors no modifications were suggested and the design was not pursued further.

Preliminary prototype C was also abandoned. The prototype was inconvenient to don and the front and back panels became displaced from the lower body during immersion (Higgins, 1983). Design features that had positive implications for future designs included:

1. The slip-over style was quick to don.

2. The air bladder held the neck opening secure alleviating the need for a closure.

3. The overlap at the neckline could be extended to decrease the amount of water channeling in through the neck opening.

4. The high standing collar provided a means for decreasing the heat exchange between the head and water, yet did not inhibit hearing or vision.

5. The prototype weighed 730 grams without CO2 cylinders and the rescue light.

6. The prototype could be folded up into the following dimensions: length 8.5 inches, width 7.5 inches, and height 4.75 inches.

Of the three prototypes tested Style B offered the most promise. Modifications were suggested to rectify existing problems, lending feasibility to the prototype and its various features. Prototype Style B could be simplified by making the following changes:

1. The air bladder should be sewn into the neckline to keep it from becoming detached at the neck edge.

2. The air bladder and garment shell should be attached at the center front waist to inhibit the air bladder from being pushed into the wearer's face during immersion.

3. The side stretch panel should be modified to facilitate donning.

4. A large toothed zipper with a large zipper tab should be used to make it easier for a man to grasp and manipulate the zipper.

5. The belt ends at the waist front should be placed further away from the zipper.

6. The storm flap should be placed under the zipper to facilitate donning.

7. A more functional piece of hardware should be used to adjust the belt at the waist.

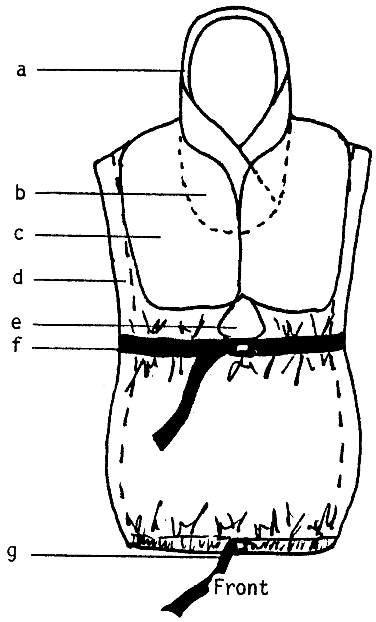
During the observation process it was noted that the hood impaired the subject's hearing, yet the thermal benefits were believed to outweigh this factor and the feature was not disregarded. The weight and storage factors were also considered. Style B weighed 805 grams excluding the CO2 cylinders and the rescue light. The folded dimensions of the prototype were: length 9.5 inches, width 7.5 inches, and height 5.75 inches. Positive reactions and suggested modifications by the FAA caused the researcher to pursue the development of Style B using water-proof fabric (Higgins, 1983).

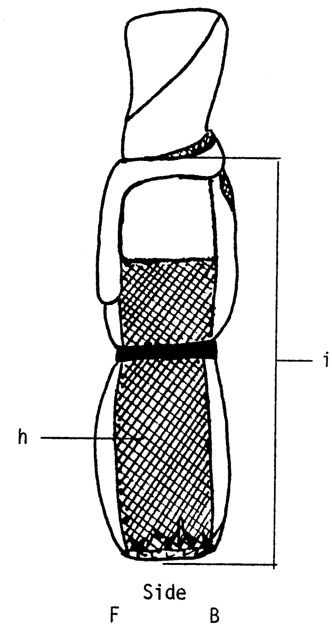
Development of Preliminary Design
Styles D and E

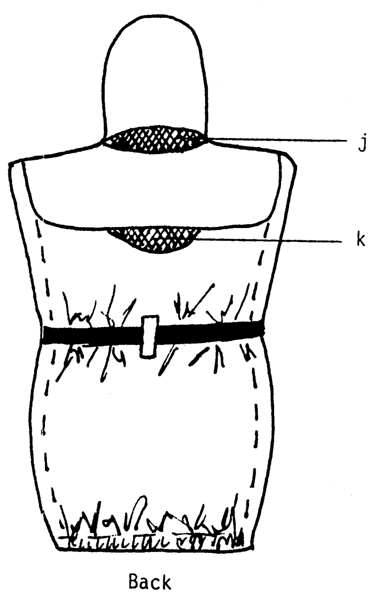
Two new preliminary designs were developed based on evaluations, reactions, and suggested modifications for preliminary prototype Styles A, B, and C. Preliminary prototypes labeled Style D and E were developed using features of Styles A, B, and C while implementing new features. Both prototypes continued to further the objectives of the project and to fulfill established design specifications.

Style D, as shown in Figure 15, possessed many of the design features described in the developmental process of Style B. Design features a, c, d, e, f, g, h, i, and j were maintained and used for the same reasons described earlier in the paper. Features c, e, g, k, and l were further developed and modified to accomodate those characteristics exhibited and situations experienced during the evaluations of earlier designs.

The air bladder (Feature c) was sewn into the seam at the neck edge to insure that the bladder would stay secure during immersion. The air







Key to Figure	Design Features
a	Hood
b	Overlapping Flap
c	Air Bladder
d	Pleat - extending the trunk length.
e	Attachment Tab
f	Belt
g	Cinch and Buckle
h	Side Stretch Panel
i	Extended Bodice Front and Back
j	Stretch Band at the base of the hood.
k	Shoulder Back Stretch Panel
l	Insulation - Thinsulate 100 (not visible)
m	Lining (not visible)

Figure 15. Style D

bladder was attached to the belt to keep the air bladder from pushing up into the wearer's face during immersion.

The belt (Feature f) was secured at the waist using a belt carrier in the center back and was held in place at the center front by a tab (Feature e). One buckle was used at the waist and one at the hem to cinch the prototype snug. The webbing running through the casing at the hem extended out through two button holes at the center front.

The side stretch panel presented a problem for donning earlier prototypes. The situation was resolved by restructuring the armscye of the side stretch panel (Feature h) so that the armhole was eliminated. The new side stretch panel began at a point halfway between the waist and the base of the previous armhole and extended to the hem. The larger armhole was designed to facilitate the donning process.

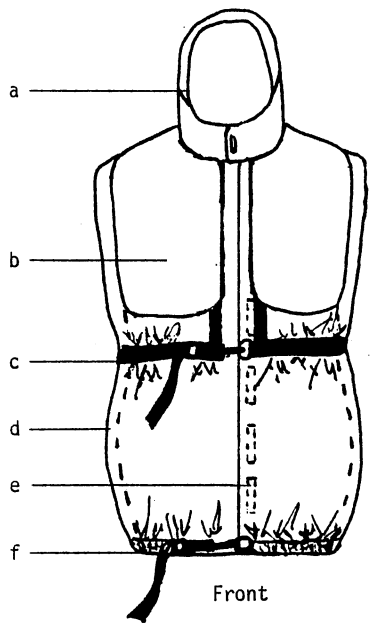
Style D was insulated and lined in the same manner as Style B. Thinsulate 100 (Feature l), a lightweight insulation, was used to decrease the weight of the prototype while maintaining some degree of thermal protection. Insulation was included in the side stretch panels and was attached at the armhole and hem but was not attached along the front and back side seams. This was to allow maximum stretch while providing thermal protection at the side seams. Gor-Tex laminant fabric was selected to construct the outer shell and lining because it was used in many types of outdoor wear. This waterproof fabric required sealing seams with a liquid sealant to prevent the influx of water during immersion. Manufacturer specifications described two fabrics composing the Gor-Tex; Ripstop/Gor-Tex weighing 1.0 ounce per yard and Tricot knit (film) weighing 1.5 ounces per yard. One hundred percent polyester rib knit was used to construct all areas requiring stretch fabric.

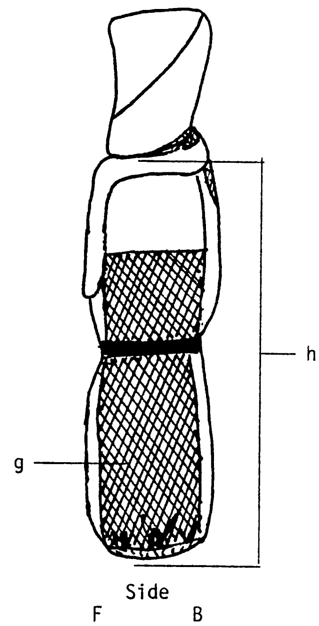
One new design feature was introduced in Prototype Style D at the center front neckline, an overlapping flap (Feature b) was developed in the form of a yoke. This feature was introduced to decrease the need for a neck closure, to facilitate donning over the head, and to reduce the influx of water.

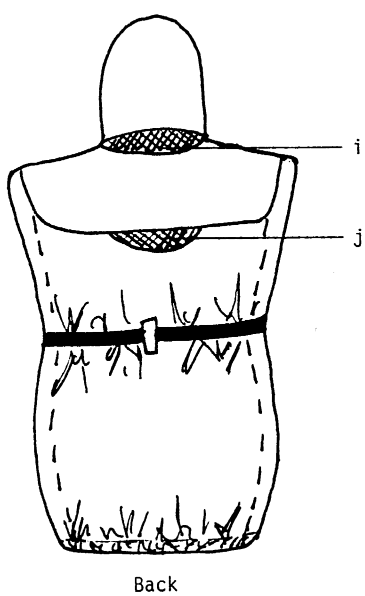
Style E, as shown in Figure 16, was similar to Style D. All features remained the same with the exception of the air bladder, the belt, the head opening, and the method of closure. Style E had a full-length center front opening which was secured by velcro. The velcro was applied to insure that the center front opening could be quickly secured. The right center front self-extension featured horizontal velcro strips placed five inches apart. Matching velcro strips were applied in a vertical position to the underside of the left front. Thus, the vest could be secured without taking the time to line up each strip of velcro.

Style E included a belt at the waist (Feature c) and a cinch at the hip (Feature f). A ring was attached to the left side of the garment front at the waist and hip and a latch was sewn to the right front. Once donned the latch could be hooked to the ring and the strap pulled tight through the buckles located next to each latch.

The air bladder (Feature b) was sewn into the neckline of Style E. A piece of webbing was attached at the center front and extended to the belt. These pieces of webbing were used to prevent the inflated prototype from being pushed up into the wearer's face during immersion. Velcro was sewn to the base of the air bladder and to the prototype to secure the device for purposes of donning.







Key to Figure	Design Features
a	Hood
b	Air Bladder
c	Belt
d	Pleat - extending the trunk length.
e	Center Front Opening
f	Cinch, Latch, and Ring
g	Side Stretch Panel
h	Extended Bodice Front and Back
i	Stretch Band at the base of the hood.
j	Shoulder Back Stretch Panel
k	Insulation - Thinsulate 100 (not visible)
l	Lining (not visible)

Figure 16. Style E

Sloper, Pattern, and Preliminary Prototype Construction for Styles D and E

The patterns for Styles D and E were drafted by altering the pattern used to construct preliminary prototype B. Both designs were constructed as full scale functional prototypes. Methods and procedures used to construct earlier prototypes were repeated in the construction of each design. Styles D and E required that each seam be sealed with a sealant to maintain the waterproof qualities of the Gor-Tex product and to protect the insulation from water seepage.

Observation of Fit and Flotation for Styles D and E

Preliminary evaluation of Styles D and E were completed at the Protection and Survival Laboratory in Oklahoma City, Oklahoma. The evaluation was conducted to evaluate universal sizing, donning time, and flotation attitude. The first phase of the evaluation process required that each design be donned in succession while standing, by a representative of the fifth, fiftieth, and ninety-fifth percentiles. Assistance was given when necessary to insure that the prototype was properly donned. A photographic record of front, back and side views was made to document fit. Donning ease and comfort were also noted.

The second phase of the evaluation process involved flotation characteristics and the donning time for each design. Representatives of the fifth, fiftieth, and ninety-fifth percentiles donned each prototype and immersed themselves in the survival tank while wearing the prototype. The procedures described for evaluating Styles A, B, and C were repeated with one exception, a donning time was recorded for Styles

D and E. Timing began when the garment was in the subject's possession and was completed when the device was secured. A donning time was recorded only for the first representative who entered the water with the prototype donned. Donning times were not recorded for later subjects because the device was already partially inflated.

The evaluation of Styles D and E was dependent upon the anthropometric measurements of the subjects used in each test situation. Anthropometric measurements were taken by Dr. Joe Young, a Research Physical Anthropoligist at the FAA facilities in Oklahoma City, Oklahoma. The anthropometric measurements are recorded in Table V, Appendix B. The identification numbers of subjects used to evaluate universal sizing were 1, 5, 8, and 11. Subject numbers 3, 7, and 11 were used to evaluate the second phase of the process. All subjects were obtained by means of a convenience sample.

Each prototype provided adequate sizing capabilities. Individuals representing the ninety-fifth percentile did not require the various sizing features developed into the design. The pleats were only slightly spread to accommodate a large girth. The various sizing characteristics made the donning process difficult for the smaller individuals because the excess bulk and size were overwhelming. Style E was confusing and clumsy to don and manipulate because of the belts, latches, and velcro. Both designs were comfortable but the subjects preferred Style D for its simplicity to comprehend and don.

The second phase of the observation and evaluation process required noting a donning time for the first representative to enter the water. The donning time for Style D was 17 seconds. The donning time for Style E was 14 seconds.

Both styles exhibited similar characteristics during immersion. Upon entering the water each design clung to the body and kept the subject afloat without inflating the air bladders. Both designs gradually filled with water and bulged away from the body. This was more obvious as each individual exited the tank; a large amount of water drained from each prototype. The large armscye allowed water to pass into and through the prototypes. There was a tendency for the cinch at the hip to pull up to the waist if it was not tightly attached. This was attributed to the webbing being difficult to adjust and manipulate through the garment openings and hardware. As mentioned for earlier designs the hood impaired hearing in both prototypes.

Each design exhibited characteristics unique to its design during immersion. Style D provided adequate buoyancy for each subject and was able to right an individual within three seconds. The tab (Feature e) used to attach the bladder and belt at the center front kept the air bladder from being pushed up into the wearer's face during immersion.

Style E did not exhibit desirable characteristics during immersion. First, the prototype did not provide adequate buoyancy or security for the subjects. The pressure exerted by the air bladder on the velcro securing the center front opening was great enough to pull the velcro loose (Figure 17). If it had not been for the latch at the waist and hem the garment would have come completely free of the wearer. The bladder did not provide support for the head and neck and separated at the center front, allowing water to channel into the face (Figure 17). Because the air bladder separated, the prototype was not able to right the wearer during a simulated unconscious state.

Figure 17. The Velcro Pulled Loose and the Bladder Separated at Center Front on Style E

Reactions to and Modifications of Preliminary Prototype Styles D and E

Preliminary prototype Style D was preferred by test subjects and the FAA over Style E. Style D was difficult to don, but less complicated than Style E (Higgins, 1983). The prototype provided adequate buoyancy, was comfortable, and fit a variety of individuals. The only discomfort was caused by the abrasive texture of the air bladder against the face and neck. The prototype weighed 1056 grams and had the storage dimmensions of 8.5 inches in length, 8.25 inches in width, and 4.75 inches in height.

Prototype Style E proved inefficient and complicated to use because of the straps and latches used to secure the prototype (Higgins, 1983). The device did not provide a sense of security. One subject even said, "It feels like I could slip through the vest." Style E weighed 965 grams and folded into the following dimensions: length 8.5 inches, width 7.75 inches, and height 5 inches.

Based on the preliminary evaluation of Styles D and E the following modifications were recommended:

1. Replace the hood with a high collar, similar to the one used in Style C (Higgins, 1983).

2. Replace velcro on Style E with large snaps.

3. Use another method for sealing seams.

4. Use a different kind of webbing and type of buckle to make the manipulation of hardware more simple.

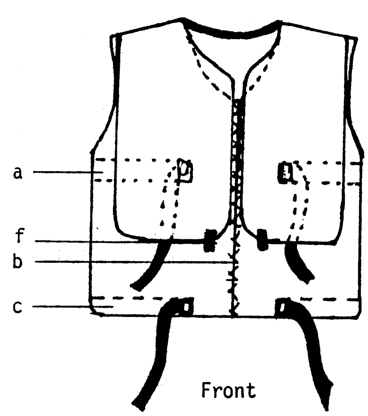
5. Secure the air bladder along the center front of Style E.

At the completion of this evaluation process the FAA changed the emphasis of the research from thermal protection and universal sizing to universal sizing and quick and accurate donning (Higgins, 1983). This new emphasis required the development of preliminary designs with emphasis on sizing, donning, buoyancy, and weight and storage. To develop designs with these characteristics the researcher once more instigated the design process by developing additional preliminary designs.

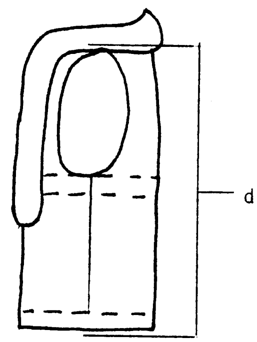
Development of Preliminary Design Styles F and G

Preliminary prototype Style F, as shown in Figure 18, was a basic vest adapted to facilitate the donning of the air bladder currently used as a flotation device by commercial airlines. The prototype length (Feature d) and the size were selected to accommodate the adult population between the fifth and ninety-fifth percentiles. A large toothed nylon parka zipper (Feature b) was placed down the center front to facilitate quick and accurate donning. A casing was applied at the chest (Feature a) and hem (Feature c) to allow a method for sizing the prototype for a variety of body sizes. The design was cinched using a smooth textured nylon webbing and lightweight aluminum buckles. Each buckle was sewn approximately three inches from the zipper to facilitate the donning process and alleviate confusion.

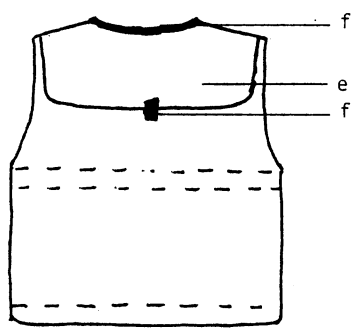
Current Federal Regulations specify that two separate air chambers be used in the construction of a life preserver so that in the event one chamber fails to inflate the other chamber will provide buoyancy for the victim. The researcher and FAA were interested in the characteristics



Front



Side
F B



Back

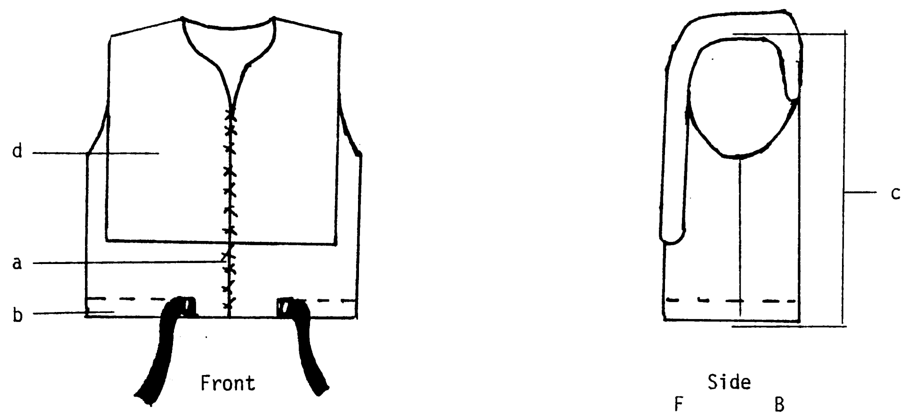
Key to Figure	Design Features
a	Chest Cinch, Buckles, and Webbing
b	Zipper
c	Waist Cinch, Buckles and Webbing
d	Garment Length
e	Air Bladder (one air chamber)
f	Paper Neck Binding and Tabs

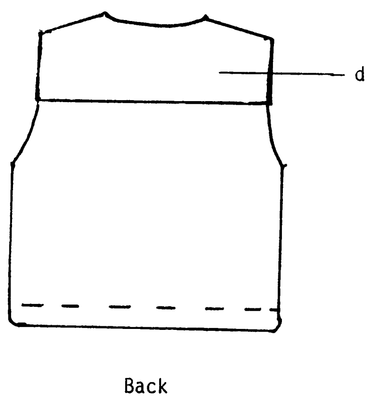
Figure 18. Style F

of a prototype using one air chamber. An approved flotation device (Feature e) was modified and attached to the garment shell at the neckline and to the zipper. To alleviate the chance that a hand would be placed between the bladder and vest, a paper binding was placed over the neck edge (Feature f). Paper tabs were also placed at the base of the air bladder on the center front and back to hold the air bladder in place during the donning process. The paper was used in place of velcro because of cost and weight.

Preliminary prototype Style F was constructed from 100 percent nylon treated to be water repellent. The fabric weighed 3.2 ounces per yard according to manufacturer specifications.

Preliminary prototype Style G, as shown in Figure 19, is a modification of Style F. One major difference is that the air bladder and vest are one piece. The bottom air chamber became a yoke on the prototype front and back (Feature d). A large toothed nylon parka zipper (Feature a) was used to secure the prototype and a casing at the hem (Feature b) was used to cinch and anchor the device during submersion. The researcher did not apply a cinch strap at the chest because of the method used to secure the air bladder. The same hardware and fabric specified for Style F were maintained for Style G.





Key to Figure	Design Features
a	Zipper
b	Waist Cinch, Buckles and Webbing
c	Garment Length
d	Air Bladder sewn in as a yoke.

Figure 19. Style G

Sloper, Pattern, and Preliminary Prototype Construction of Styles F and G

A new sloper was drafted for preliminary prototypes F and G. Methods described by Hanford (1974) were used to develop the sloper. Anthropometric measurements used to construct the sloper were taken from the ninety-fifth percentile listed in Table I. Table III refers to the measurements used to draft the pattern, as well as to the final dimensions of the sloper. Final pattern measurements were adjusted for the purpose of smoothing and trueing up pattern lines. Chest and waist dimensions were increased slightly to accommodate a greater portion of the population. The increase did not greatly affect the weight or storage dimensions of the prototype.

Observation of Fit and Flotation for Styles F and G

Preliminary evaluations of Styles F and G were completed at the Protection and Survival Laboratory in Oklahoma City, Oklahoma. The purpose of the evaluation was to observe subjects donning the prototypes and to use the prototypes under simulated conditions. Two separate sets of procedures were used to evaluate each prototype. The procedures used to evaluate Styles A, B, and C were repeated to evaluate Style F. A more detailed evaluation was not completed because the researcher and the FAA were primarily interested in the flotation characteristics of a life vest providing one air chamber for buoyancy. The researcher and FAA were aware that a device such as this would require changing current FAA specifications.

TABLE III

MEASUREMENTS USED TO CONSTRUCT SLOPER AND PATTERNS FOR STYLES F, G, AND H

Portion of Body	Measurement for 95th Percentile	Final Pattern Measurements
Neck Circumference	16.5	
Shoulder Length	7.4	7.0
Shoulder Width	17.3	17.0
Back Shoulder	17.8	18.0
Chest Circumference	43.2	51.5
Chest Breadth	14.4	26.5
Waist Circumference	39.6	51.0
Waist Front Length	17.4	16.5
Waist Back Length	20.1	24.5
Scye Circumference	21.0	26.0

Note: Measurements provided in inches.

Style G was evaluated using the same procedures described in the evaluation of prototype Styles D and E. The evaluation of Style G also included viewing a video tape of a donning study conducted by the FAA which used prototype Style G.

The anthropometric measurements for individuals used to evaluate prototype Styles F and G are recorded in Table V, Appendix B. The identification number of the subject used to evaluate Style F was 6 and subject numbers 1, 3, 4, 7, 8, 9, and 11 participated in the evaluation of Style G. All subjects were obtained by means of a convenience sample.

Prototype Style F provided more than adequate sizing capabilities for Funkhouser. Difficulties encountered resulted from the casing catching in the buckles while adjusting the fit of the prototype. The prototype provided buoyancy for the wearer, supporting the head and neck above the water's surface. No discomfort was experienced during immersion. The prototype did exhibit a characteristic previous designs possessed, the entire device pulled up on the torso during submersion. This prototype did not become as distorted on the body as earlier designs, since it stayed snug against the body. The paper binding and tabs stayed secure during donning and broke loose when the air bladder was inflated, allowing the bladder to pull up around the head and neck (Figure 20).

Prototype Style G provided good sizing capabilities for each representative of the fifth, fiftieth and ninety-fifth percentiles. The extreme size of the prototype was almost overwhelming for representatives of the fifth percentile. The base of the armhole dropped below the bust line of the smaller individuals. Adjusting the

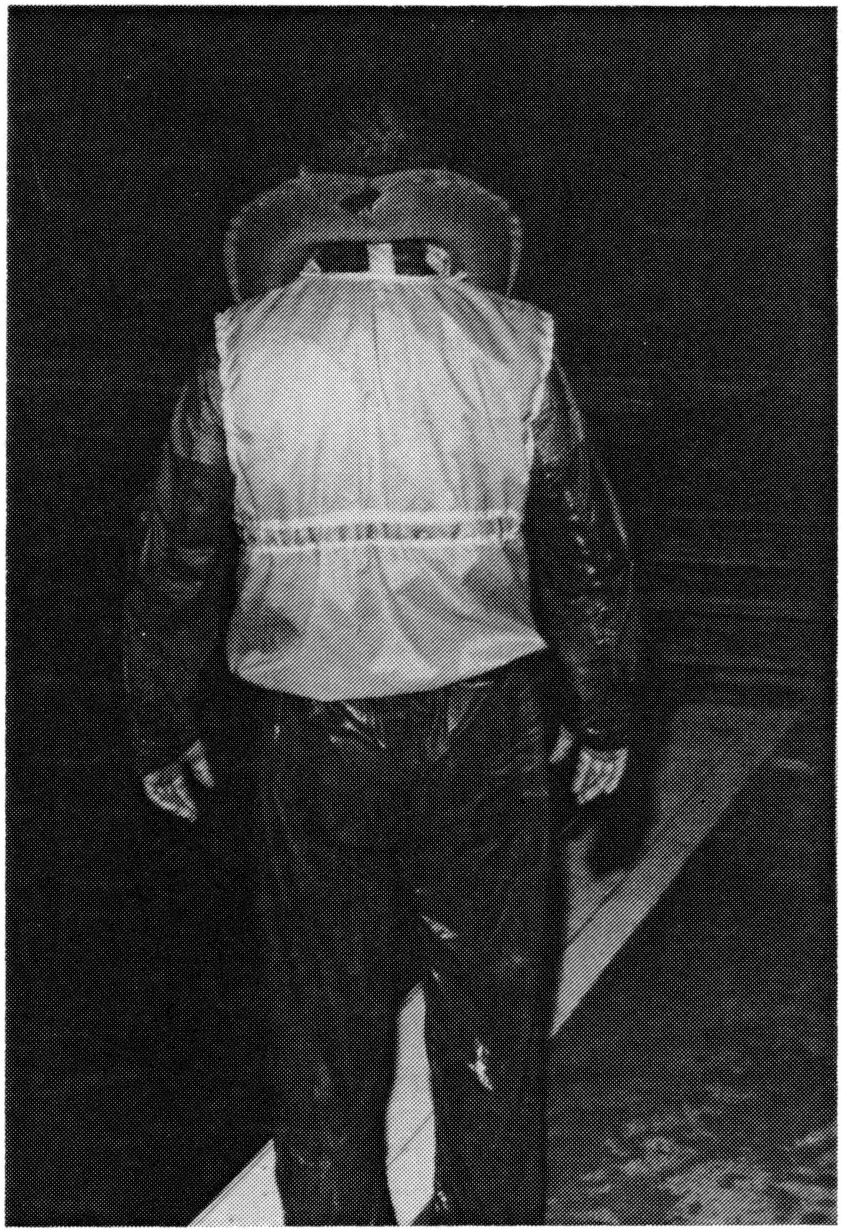


Figure 20. Paper Binding Broke Loose on Style F

prototype snug against the body was difficult because of the excessive amount of fabric gathered up by the cinch at the waist. In a 1984 donning study conducted by the FAA, a woman who was eight and one-half months pregnant was included in a group of test subjects, and the prototype fit this woman. An earlier evaluation of the donning capabilities of Style G indicated the design "...was easy to don and adjust to size" (Higgins, 1983).

Style G was used in a donning study completed by the FAA in 1984. The mean donning time for the preliminary design was 20.55 seconds.

Style G provided buoyancy and supported the head and neck for all subjects tested. Style G was capable of righting an individual within 2.5 seconds without causing discomfort for the wearer. The only discomfort reported was due to the abrasive edge of the air bladder next to the face and neck. During immersion, the air bladder caused the entire prototype to pull up on the torso and contributed to the front of the garment pulling up and away from the body (Figure 21).

Reactions to and Modifications of Preliminary Prototype Styles F and G

The FAA, researcher, and test subjects had positive reactions toward preliminary prototypes F and G. The styles were easy to don and adjust while providing universal sizing and buoyancy. The designs were lighter weight than previous designs (Appendix C, Table VI). Style F weighed 590 grams and Style G weighed 580 grams. The folded dimensions of prototype F were: length 9.5 inches, width 8 inches, and height 3 inches. The folded dimensions of Style G were: length 8.5 inches, width 6.75 inches, and height 3.5 inches.

Figure 21. Style G Pulled Up and Away from the Body

Prototype Style F provided the researcher and FAA the opportunity to observe the characteristics of a prototype providing only one air chamber for buoyancy. Since the researcher was using current Federal Regulations as a guide for design criteria this prototype was not pursued further.

Style G involved using the lower air chamber as a yoke on the garment front and back. This design feature was instigated to reduce excess fabric, weight, and confusion caused by the movement of two loose air chambers on the exterior of the garment shell. Preliminary prototype Style G was the least complicated of the preliminary designs to don. With minor modifications this design offered the greatest possibility for accomplishing the objectives of the research.

Modifications to implement on the design:

1. A chest cinch strap should be applied to hold the air bladder secure against the body.

2. The casing for each cinch should be applied to the exterior on the garment back. The opening for each casing should be located at the side seams. A tab applied to the center of each garment side front will hold the webbing in place and function as a guide for cinching the prototype snug against the body.

3. Use a lightweight disposable fabric for the prototype shell.

Preliminary design work allowed the researcher to develop and evaluate various design ideas trying to locate one design which most realistically accomplished the objectives of the study and fulfilled the established design specifications. The positive reaction to Style G enabled the researcher to proceed with the design process illustrated in Figure 2.

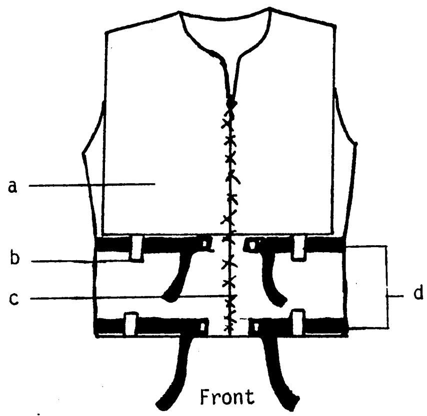
Selection and Development of Prototype

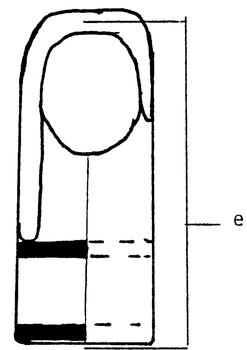
Design Style H

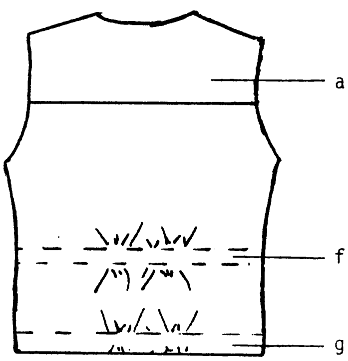
Prototype Style H was developed as a result of all preliminary prototypes designed, constructed and evaluated. Style H, as illustrated in Figure 22, provided for a light weight flotation device that would fit eighty percent of the population, could be donned quickly, and would provide adequate buoyancy.

This prototype length (Feature e) was designed to accomodate the ninety-fifth percentile of the U.S. adult population. Belt carriers at the center of each side front (Feature b) and a casing placed on the exterior of the garment back at the chest (Feature f) and hem (Feature g) provided a method for adjusting fit and anchored the entire device to the body. The chest strap (Feature f) also functioned to hold the air bladder in place during immersion. A snug fit was achieved by using a smooth textured nylon webbing and aluminum buckles (Feature d) to cinch the prototype. A three inch piece of elastic applied to the center of each piece of webbing allowed for the slight preadjustment of the prototype for the smaller individual while still providing full sizing capabilities for the larger individual. Quick and accurate donning was achieved by applying a large toothed nylon zipper at the center front (Feature c).

Buoyancy was provided by modifying an existing approved flotation device. The bottom chamber of the air bladder (Feature a) was used as a yoke on the garment front and back. This design feature was used to simplify the look of the prototype while facilitating the donning process.







Key to Figure	Design Features
a	Air Bladder sewn in as a yoke.
b	Belt Carrier
c	Zipper
d	Chest and Waist Cinch, Buckles and Webbing
e	Garment Length
f	Garment Back Casing at Chest
g	Garment Back Casing at Waist

Figure 22. Style H

The shell of Style H was constructed of a disposable non-woven product called Tyvek®. Tyvek is a spunbonded, high-density polyethylene fiber (Wingate, 1979) produced by E.I. DuPont de Nemours and Company Incorporated. This durable and tear-resistant product is used for disposable industrial and medical garments (Linton, 1973). The fabric can be sewn, adhesively bonded, coated, laminated, and heat-sealed (Wingate, 1979). Tyvek is available in weights of 1.5 to 3.0 ounces per square yard.

Construction of Prototype Style H

Prototype Style H was constructed from the pattern used to construct preliminary prototype Style G. Style H was constructed as a full scale functional prototype using methods and procedures followed in the construction of preliminary designs.

CHAPTER IV

EVALUATION OF PROTOTYPE STYLE H

The purpose of this project was to develop a prototype life vest for the Federal Aviation Administration. The prototype was designed to provide universal sizing, comfort, buoyancy, quick and accurate donning, and limited weight and storage. The evaluation of the prototype was done in cooperation with the FAA.

Methods and Results of Evaluation

The evaluation of prototype Style H was completed at the Protection and Survival Laboratory in Oklahoma City, Oklahoma. The evaluation involved four phases: weighing and measuring the dimensions of the folded prototype; viewing the universal sizing capability of the design; donning the prototype on a representative of the fifth, fiftieth, and ninety-fifth percentiles; and immersing the donned prototype.
A form (Appendix D) was developed to record the observations, reactions, perceptions, and experiences of the test subjects, the FAA, and the researcher. The evaluations were documented by photographs taken during each phase of the evaluation process.

Weight and Storage

The first phase of the evaluation process required weighing and obtaining the storage dimensions of the prototype. The prototype was weighed on a Metler Balance. The prototype was unconditioned prior to weighing due to the lack of a conditioning room and the minimal water retention of synthetic materials. Each prototype, without gas cylinders and a rescue light, was weighed on three separate occasions. The average weight was recorded in Appendix C, Table VI. To obtain the storage dimensions of Style H, the prototype was folded into a compact unit and placed in an 11.5 inch X 12.5 inch plastic zip lock bag. The height, length, and width were measured and recorded in Table VI. The average weight of Style H was recorded as 546 grams and the folded dimensions were: length 8.75 inches, width 6.25 inches, and height 3.75 inches..

Universal Sizing

The second phase of the evaluation process required individuals representing the fifth, fiftieth, and ninety-fifth percentiles to don the prototype so that universal sizing could be evaluated. Subjects were obtained through a convenience sample. The anthropometric measurements of the subjects were taken by Dr. Joe Young, Research Physical Anthropologist at the FAA in Oklahoma City, Oklahoma. The identification numbers of subjects used to evaluate universal sizing were 1, 3, 4, 5, 8, and 9, and their measurements are recorded in Appendix B. In preparation for donning, oral donning instructions were given to each subject. Once donned, the prototype was photographed from the front, back, and side. The researcher's, the FAA's, and the subjects' perceptions of fit and comfort were recorded.

The prototype fit all representatives of the adult population sampled. The sizing capabilities provided ample fit for the ninety-fifth percentile and left more than an adequate amount of room for representatives of the fifth percentile. The size of the garment was so extensive on these persons that it was difficult to cinch the device snug against the body. Figure 23 illustrates how large the device is on a representative of the fifth percentile. The prototype did not provide any discomfort at the neck, armscye, chest, or waist.

Donning

In the fall of 1984, a donning study was completed by the Protection and Survival Laboratory of the FAA located in Oklahoma City, Oklahoma. Prototype Style H developed by the researcher was included in this study. Two groups of twenty-five individuals were used to test the donning time of the prototype. A video tape of a flight attendant administering donning instructions was used to instruct each subject on the location and use of the prototype. The test was conducted in a simulated passenger cabin of a commercial aircraft. The simulated arrangement involved two rows of three seats. Each test subject was seated in the second row in the middle seat and asked to buckle his seat belt. At the sound of a buzzer the individual was to retrieve the life vest from its stowed location, remove the device from the sealed plastic bag, and then don the life vest. The donning time was calculated from the moment the life vest cleared the bag until the zipper was completely zipped. Subjects participating in the study were obtained through the State Employment Agency. Personal data regarding each test subject and his personal donning time is recorded in Table IV.

This donning study was used in the third phase of the evaluation of prototype H. The evaluation consisted of viewing the video tape of the

Figure 23. The Extreme Size of Style H on a Representative of the Fifth Percentile

TABLE IV

PERSONAL DATA REGARDING TEST SUBJECTS USED IN THE FAA'S DONNING STUDY OF STYLE H

Subject Number	Age	Sex	Weight	Donning Time in seconds
004	22	M	139.50	29.5
012	23	F	105.00	21.3
014	26	M	201.00	19.2
033	20	F	149.50	16.9
003	28	F	102.50	12.2
016	36	M	216.00	14.0
028	32	M	217.00	14.4
035	30	M	182.00	14.6
064	34	F	123.50	14.0
075	37	F	189.50	15.7
040	44	M	197.50	30.0
058	40	M	137.75	16.0
077	41	F	213.50	16.6
080	42	F	116.00	13.1
095	40	F	124.00	17.5
034	57	M	178.50	14.8
043	58	F	94.00	20.9
073	56	F	133.00	23.0
088	53	M	150.75	31.2
089	50	M	211.00	17.8
030	66	M	167.50	18.9
041	63	M	148.50	15.7
071	67	F	119.00	29.1
096	64	F	171.75	17.4
101	60	F	124.5	31.7

Note:

Range	12.2 - 31.7
Mean	19.42
N	25
Failures	0

donning study completed by the FAA. The mean donning time for the prototype was determined. In addition, individual problems and circumstances which inhibited the donning process were noted.

Quick and accurate donning was inhibited by the zipper and cinch straps of Style H. The zipper guide was difficult to align and see under an extended abdomen. Cinch straps easily slide through the casing and carriers but, when pulled snug on the small individual, the fabric gathered at the center front rather than being evenly distributed around the body. The ends of the webbing became tangled with the cylinder pulls on the air bladder and were concealed within the folds of the vest while seated.

Three situations involving the air bladder continually occurred during the donning study. The modified flotation device applied to Style H was constructed in such a manner that an arm could be easily placed through the neckedge between the two air chambers. The loose corners on the back of the top air chamber caused some confusion by flapping loose and drawing attention away from the donning process. The weight of the air bladder caused some difficulty when zipping the prototype. The bladder continually folded to the inside of the prototype and had to be pulled out to completely zip the zipper closed. Even with the difficulties described, the mean donning time for prototype Style H was 19.42 seconds.

Buoyancy

The final phase of the evaluation process consisted of observing flotation characteristics of the prototype during immersion. The prototype was donned by a representative of the fifth, fiftieth and ninety-fifth percentiles and immersed in the survival tank. Subjects, numbers 2, 6, and 10 were obtained through a convenience sample and their anthropometric measurements are recorded in Appendix B. Each individual was responsible for easing into the tank, gently treading water, making four turns in the tank, simulating unconsciousness, and then swimming around the tank actively for a couple of minutes. Upon exiting the tank the subjects were asked not to adjust the prototype in any manner allowing the researcher to note the fit of the prototype. Each subject was questioned about fit, comfort, and security. A video tape of the session was recorded to document the flotation characteristics of prototype Style H.

During submersion, prototype H was able to right an individual within three seconds while providing support for the head and neck. The cinch applied at the chest functioned well, holding the base of the air bladder down. One subject said, "You can not even feel the straps." As seen in earlier preliminary evaluations, the prototype pulled up on the torso, which caused the gathers at the garment front to pull out from under the strap at the hem. No discomfort was experienced from the displacement of the prototype. Discomfort experienced was due to the abrasive texture of the air bladder upon the face and neck. The inflated air bladder also inhibited the hearing of individuals because of the prototype's positioning against the ears. When subjects were asked if the prototype provided a sense of security all replied, "Yes."

Summary

The evaluation of prototype Style H indicated that the design met the objectives of the research and that the design conformed to a number of current FAA regulations regarding flotation equipment used on board commercial airlines. The prototype weighed 546 grams and was 8.75 inches in length, 6.25 inches in width, and 3.75 inches in height. The prototype met the design objective of universal sizing by fitting representatives of the fifth, fiftieth and ninety-fifth percentiles. The mean donning time for the prototype was 19.42 seconds. Difficulties in donning the prototype involved the zipper, cinch, and air bladder. The prototype exhibited good flotation characteristics by righting an individual within three seconds while providing support for the head and neck. The only discomfort encountered was the abrasive texture of the air bladder next to the face and neck. The evaluation of prototype Style H revealed design features requiring modification and suggested areas for future research.

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The purpose of this study was to develop a prototype life vest for the Federal Aviation Administration. The prototype life vest was designed to provide universal sizing, buoyancy, quick and accurate donning, limited weight and storage, and thermal protection. After work had started on preliminary designs, the FAA changed the emphasis of the research, asking the researcher to deemphasize thermal protection and to focus work in the areas of universal sizing and quick and accurate donning. Seven preliminary prototype designs were developed and constructed as functional life vests. The progressive development of preliminary prototypes influenced the selection, development, and construction of the final prototype. An evaluation of the prototype concluded that the design was a positive alternative to the design problem initiated by the FAA.

Conclusions

The researcher concluded that a life vest could be developed with the characteristics expressed by the FAA while maintaining many of the current FAA regulations regarding flotation equipment used on commercial airlines. Prototype Style H was a culmination of the most realistic and feasible design features used in the development of preliminary prototype designs.

Weight and Storage

The results of this study indicated that weight and storage dimensions can be kept to a minimum. The development of each prototype was influenced by the material and design of the preceding style. Table VI in Appendix C illustrates how each style progressively weighed less and required less storage space than previous designs. For example, Style A weighed 913 grams and possessed the dimensions of 14.25 inches in length, 11.00 inches in width, and 8.0 inches in height, while Style H weighed 546 grams and was 8.75 inches in length, 6.25 inches in width, and 3.75 inches in height.

The one factor which most readily affected weight and storage was the fabric used to construct each prototype. Style H, constructed of a disposable material called Tyvek illustrated how a lightweight non-woven product could be used as a source for future designs. This product which can be coated, laminated, and heat sealed (Wingate, 1979) could produce a life vest which is water repellent and air tight.

Universal Sizing

Prototype Style H provided adequate sizing capabilities. The use of cinch straps at the chest and waist allowed individuals representing the fifth and fiftieth percentiles to adjust the fit of the prototype while maintaining a design which accommodated the ninety-fifth percentile. If this design were to be accepted by commercial airlines, some type of flotation device for children and passengers who are physically smaller than the fifth percentile or physically larger than the ninety-fifth percentile would have to be provided.

Quick and Accurate Donning

The design of prototype Style H enabled the quick donning of the prototype life vest. The following minor modifications to this design would increase the donning accuracy of Style H.

1. Install a large toothed zipper with a large, long zipper guide.

2. Shorten straps and apply large tabs at the end of each strap decreasing the confusion between the strap ends and the cylinder pulls.

3. Extend the elastic at the center back strap from one side seam to the other preadjusting the device for the fifth and fiftieth percentiles, while leaving it fully expandable for the ninety-fifth percentile. The elastic would aid in the distribution of gathers caused by cinching the prototype snug against the body.

4. Sew or bind the two air chambers together at the neck edge so that an arm can not be pushed through the opening.

5. Attach snaps on the back, at the corners of each air chamber to hold the top chamber in place.

6. Develop a prototype in which the bottom air chamber is a part of the vest shell.

Buoyancy

Prototype Style H provided buoyancy for all individuals submerged in a survival tank while wearing the prototype. The design provided two air chambers and was capable of righting an individual within three seconds. The prototype was comfortable to wear moving or motionless in the water. The only discomfort experienced was due to the abrasive texture of the air bladder next to the face and neck. A softer fabric or a neck binding applied to the air bladder would remove the discomfort.

During submersion, the prototype rode up on the torso supporting the need for one or both cinch straps. The straps kept the prototype snug against the body and decreased the chance that an individual might slip through the device. The chest strap also helped to position the air bladder so that it did not push up into the face or cause water to channel in that direction.

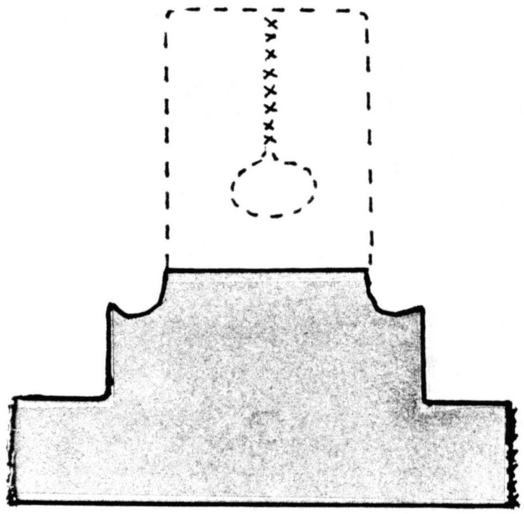
Thermal Protection

In the event the FAA decided to pursue the option of thermal protection, prototype Style H could be modified. Insulation materials could be inserted to the shaded areas of option A (Figure 24) or to the entire life vest as illustrated in option B (Figure 24). The design selected would depend on the amount of thermal protection desired and the amount of excess weight that the commercial airlines would be willing to accept.

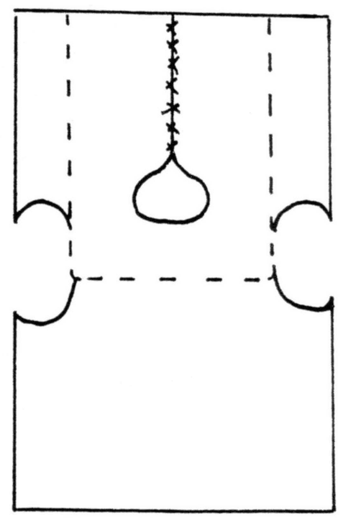
Recommendations for Future Research

The following subject areas have been identified for the continued research of a life vest which would provide universal sizing, buoyancy, quick and accurate donning, limited weight and storage, and thermal protection.

1. Design an air bladder that does not impair hearing or cause discomfort while inflated. The design should involve developing lighter weight hardware such as gas cylinders and the triggering mechanism for inflating the air bladder.



Option A



Option B

Figure 24. The Proposed Insulation of Style H

2. Focus on the development of hardware that is simple to understand and manipulate, and light in weight.

3. Test various fabrics for waterproof qualities, airtight qualities, thermal qualities, heat tolerance, toxicity, and weight.

4. Test various construction methods to determine the most efficient means for sealing seams and applying hardware.

5. Develop a design which would provide thermal protection and test the design for the amount of thermal protection provided.

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APPENDIXES

APPENDIX A

ANTHROPOMETRIC ILLUSTRATION OF

MEASUREMENTS IN TABLE I

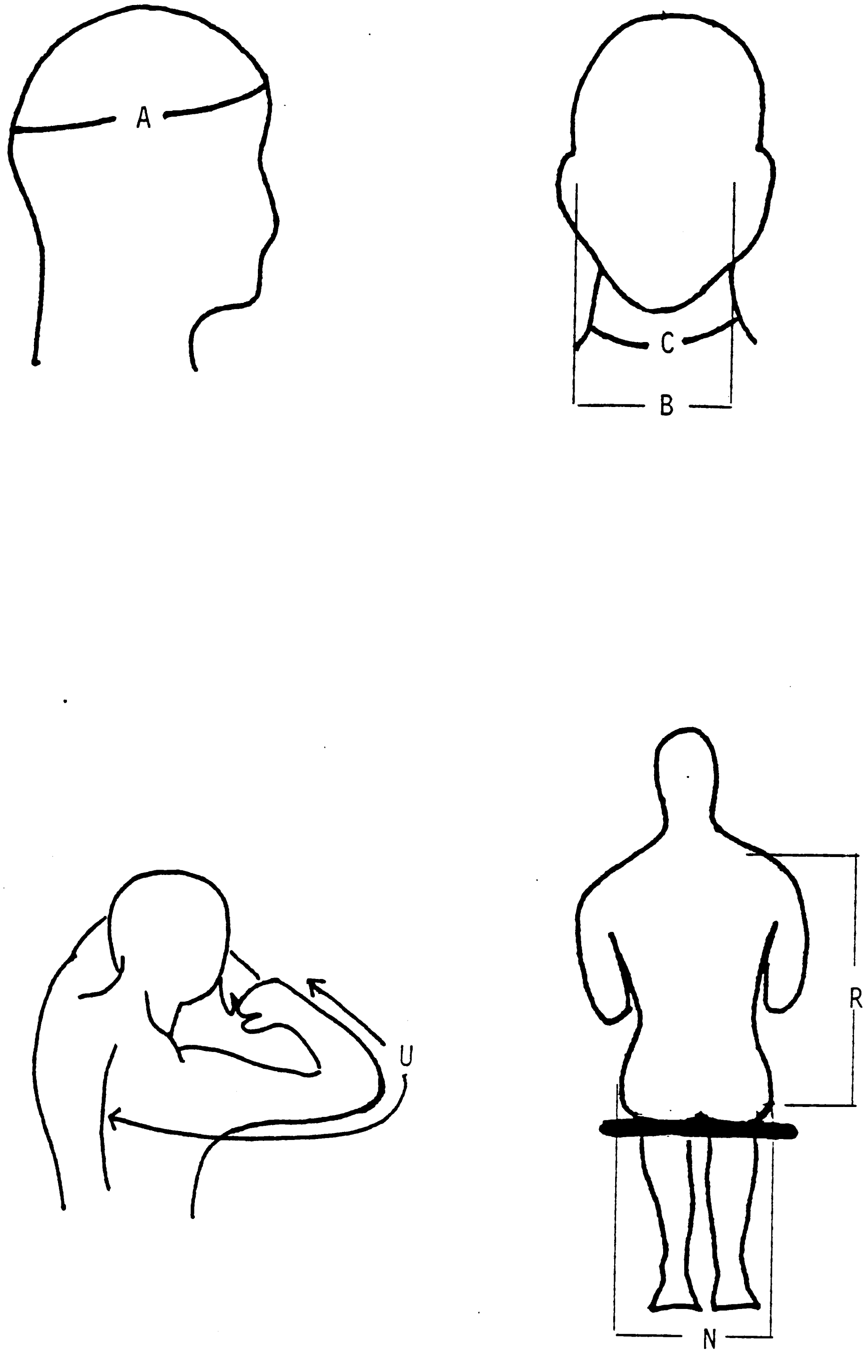

Figure 3. Anthropometric Illustration of Measurements in Table I

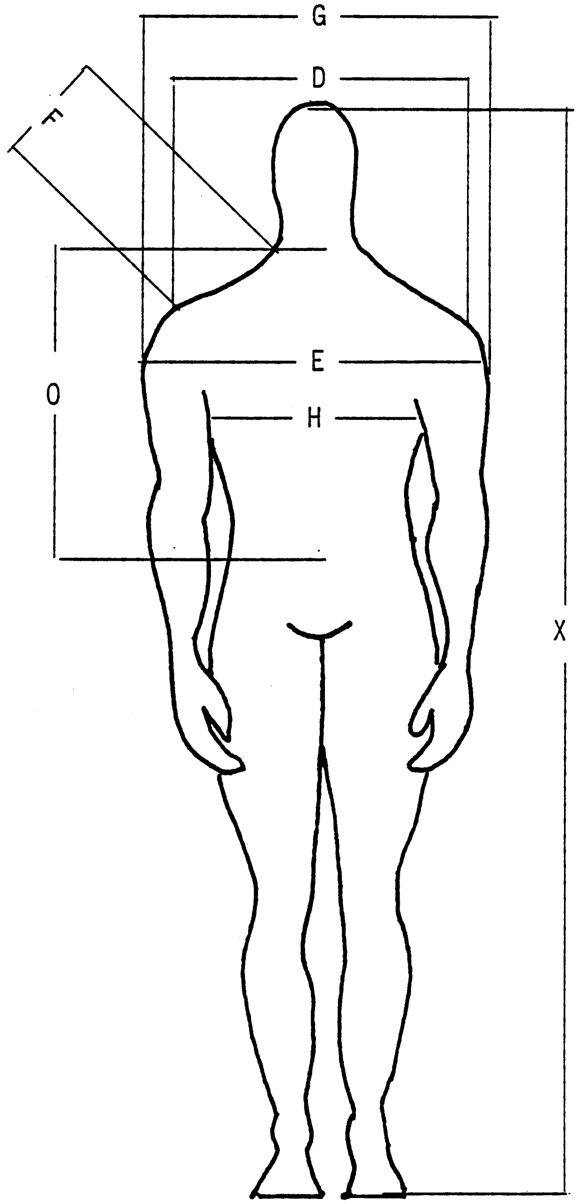

Figure 4. Anthropometric Illustration of Measurements in Table I

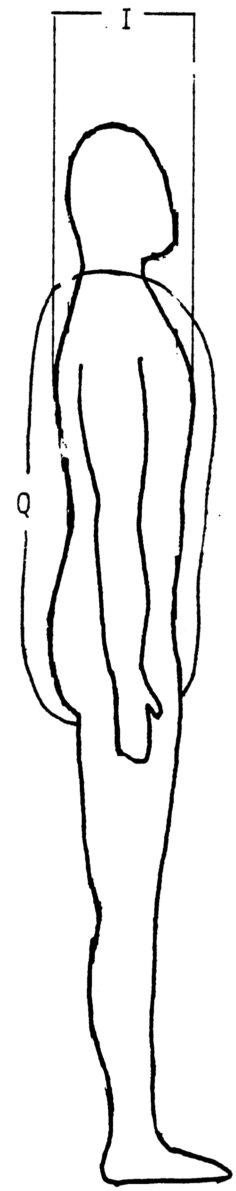

Figure 5. Anthropometric Illustration of Measurements in Table I

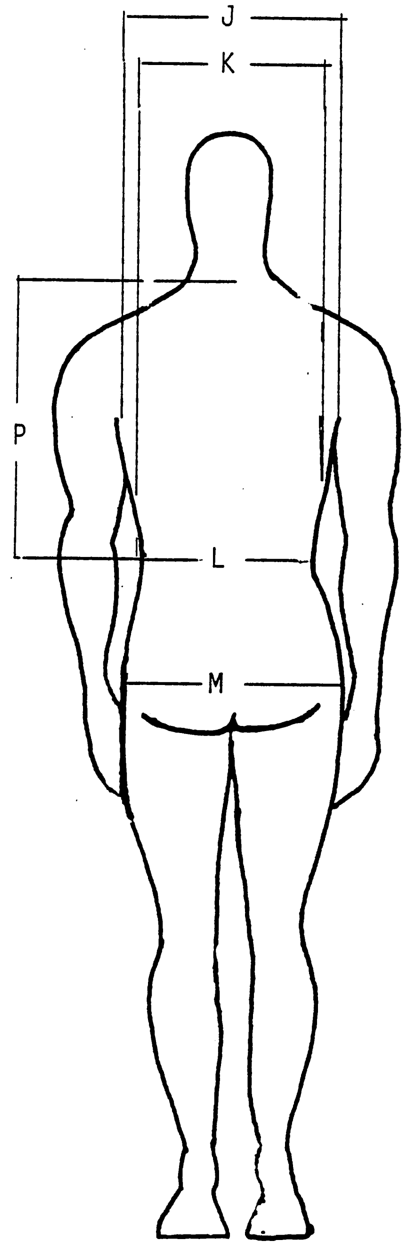

Figure 6. Anthropometric Illustration of Measurments in Table I

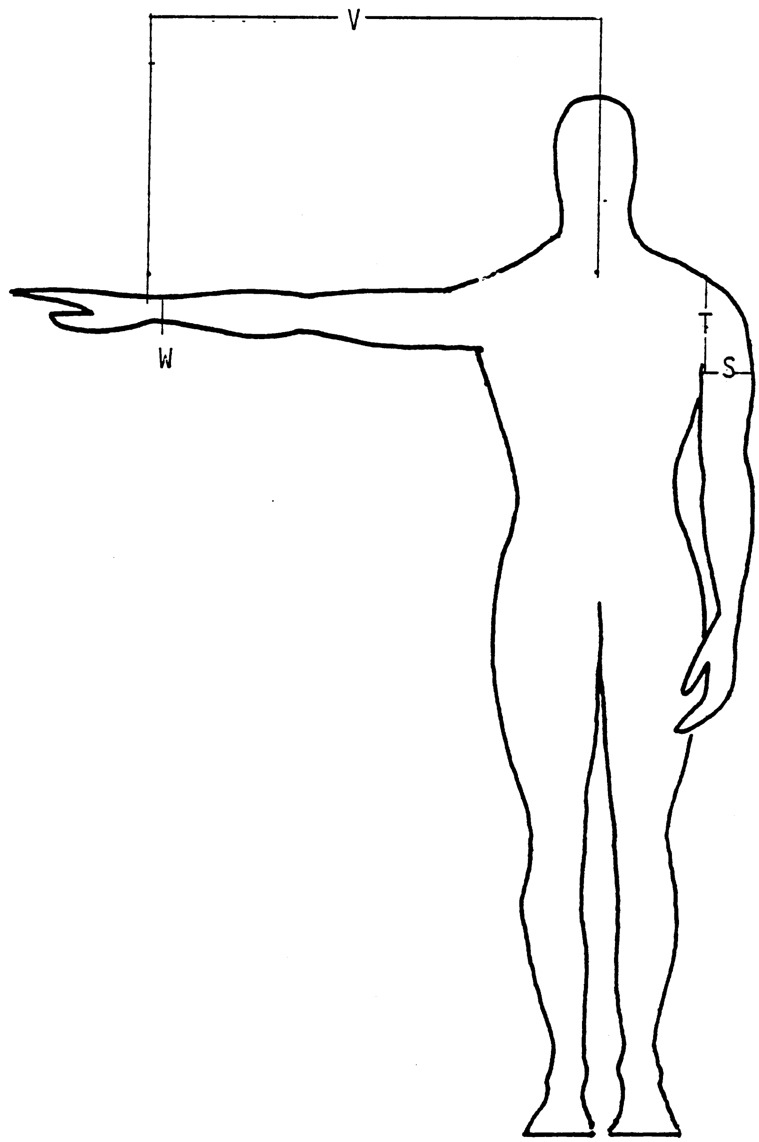

Figure 7. Anthropometric Illustration of Measurements in Table I

APPENDIX B

ANTHROPOMETRIC MEASUREMENTS FOR SUBJECTS USED TO EVALUATE PROTOTYPES

TABLE V

ANTHROPOMETRIC MEASUREMENTS FOR SUBJECTS
USED TO EVALUATE PROTOTYPES

Percentile of Population	5th					50th				95th	
Subject Number	1	2	3	4	5	6	7	8	9	10	11
Stature	62.0	59.5	63.7	60.0	65.0	67.0	67.0	71.0	74.3	69.0	73.0
Weight	91.1	95.5	110.2	112.2	136.9	153.7	154.3	179.3	182.6	214.3	229.8
Breadth											
Biacromal	13.0	12.4	13.5	12.2	13.7	14.3	14.4	14.7	13.6	15.1	16.1
Chest	5.9	10.1	10.6	10.4	11.0	13.0	12.6	13.2	13.2	15.2	14.6
Waist	8.2	8.3	9.4	9.0	9.3	12.5	12.2	12.6	12.8	13.9	13.9
Hip	12.6	11.7	12.6	12.2	13.4	14.7	12.9	13.9	15.1	14.8	15.3
Depth											
Chest	7.9	8.9	8.6	9.3	10.2	9.6	9.1	9.5	10.5	12.6	10.8
Waist	5.9	6.7	6.2	7.3	7.8	9.5	9.5	10.4	10.2	12.4	10.8
Hip	8.2	8.7	8.3	9.1	9.7	9.8	10.6	9.8	11.0	12.2	11.0
Circumference											
Neck	11.2	11.6	12.4	13.2	12.6	15.6	14.5	15.4	14.6	15.6	16.0
Chest	31.1	34.1	34.1	35.0	36.9	39.2	38.8	40.4	39.4	46.9	44.2
Waist	23.3	24.8	26.1	26.8	27.9	35.5	37.3	39.6	37.6	42.5	42.3
Hip	33.4	32.7	35.1	35.3	37.4	39.4	39.4	40.0	41.6	44.1	44.5
Length											
Shoulder	4.3	4.3	4.6	4.3	4.2	5.0	5.6	5.3	5.1	5.2	6.1

* Measurements are given in inches and pounds.

APPENDIX C

WEIGHT AND STORAGE DIMENSIONS

FOR ALL DESIGNS

TABLE VI

WEIGHT AND STORAGE DIMENSIONS
FOR ALL DESIGNS

Style	Weight in Grams	Storage Dimensions Inches
A	913	14.25 Length 11.00 Width 8.00 Height
B	805	9.50 Length 7.50 Width 5.75 Height
C	730	8.50 Length 7.50 Width 4.75 Height
D	1056	8.50 Length 8.25 Width 4.75 Height
E	965	8.50 Length 7.75 Width 5.00 Height
F	590	9.50 Length 8.00 Width 3.00 Height
G	580	8.50 Length 6.75 Width 3.50 Height
H	546	8.75 Length 6.25 Width 3.75 Height

APPENDIX D

EVALUATION FORM

EVAULATION FORM

I. Weight and Storage

A. Weight: _________ grams.

B. Storage Dimensions:

1. Length _________ inches

2. Height _________ inches

3. Width __________inches

C. Comments:

II. Universal Sizing

	Poor	Adequate	Good
A. Fit:			
Fifth Percentile	( )	( )	( )
Fiftieth Percentile	( )	( )	( )
Ninety-fifth Percentile	( )	( )	( )
B. Comfort:			
Neck	( )	( )	( )
Armscye	( )	( )	( )
Chest	( )	( )	( )
Waist	( )	( )	( )

C. Comments:

III. Donning

A. Donning time: _________ seconds.

	Poor	Adequate	Good
B. Manipulation of Hardware:			
Cinch at Chest	( )	( )	( )
Cinch at Waist	( )	( )	( )
Zipper	( )	( )	( )
C. Perceived understanding and comprehension.	( )	( )	( )

D. Comments:

IV. Flotation Characteristics

A. Prone Position within ________ seconds.

	Poor	Adequate	Good
B. Comfort:			
Neck	( )	( )	( )
Armscye	( )	( )	( )
Chest	( )	( )	( )
Waist	( )	( )	( )

C. Buoyancy Yes ( ) No ( )

D. Sense of Security Yes ( ) No ( )

E. Displacement during immersion. Yes ( ) No ( )

F. Comments:

VITA 2

Karla Louise Knoepfli

Candidate for the Degree of

Master of Science

Thesis: THE DEVELOPMENT OF UNIVERSALLY-SIZED PROTOTYPE LIFE VEST FOR THE FEDERAL AVIATION ADMINISTRATION

Major Field: Clothing, Textiles, and Merchandising

Biographical:

Personal Data: Born in Norman, Oklahoma, May 23, 1960, the daughter of Walter and Isobel Knoepfli.

Education: Graduated from Norman High School, Norman, Oklahoma in May, 1978; received Bachelor of Science degree in Clothing, Textiles, and Merchandising from Oklahoma State University, May, 1982; completed requirements for Master of Science degree at Oklahoma State University, May, 1985.

Professional Experience: Head Resident, Single Student Housing, Oklahoma State University, 1982-85; Assistant Head Resident, Single Student Housing, Oklahoma State University, 1981-82.

Professional Organizations: Phi Kappa Phi, Omicron Delta Kappa, Omicron Nu, Phi Upsilon Omicron.