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FLOTATION AND SURVIVAL EQUIPMENT STUDIES

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The work reported in this paper was performed under Task AM-B-77-PRS-15 and preceding tasks in this area.

16. Abstract

This report is a collection of various studies, conducted over 15 years, of flotation and survival equipment used or proposed for aviation application, including developmental and prototype designs. Results of these studies were presented at scientific meetings and/or published in preprints or proceedings with limited distribution. Information obtained from several of the included studies is being used in the development of revised flotation equipment standards.

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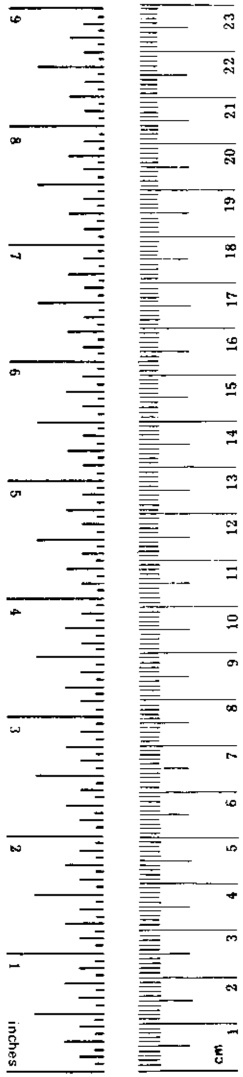
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

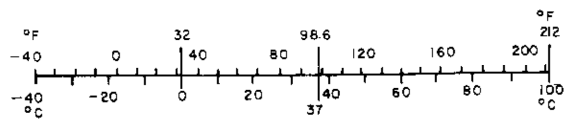
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2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

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



Approximate Conversions from Metric Measures

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



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FLOTATION AND SURVIVAL EQUIPMENT STUDIES

INTRODUCTION

This is a collection of reports of various studies of flotation and survival equipment used or proposed for aviation application, including developmental and prototype designs. These studies were generally designed and oriented toward obtaining answers to a particular question or problem with respect to reliability and protective capability of a given device or procedure, or to advance the state-of-the-art in survival and safety, and were for use in air or water transportation industry and/or within the Federal Government. Certain of these reports were presented at scientific meetings and/or published in preprints or proceedings with limited distribution. Information obtained from several of the included studies is being used in the development of revised flotation equipment standards. As some of these studies were preliminary in nature and were conducted over a period of 15 years, information contained in these reports is subject to additional evaluation or change on review of the data, conduct of additional testing, or receipt of additional facts.

SYNOPSES OF REPORTS

Aircraft Flotation Seat Cushion Evaluation, Memorandum Report No. AAC-119-77-3(S), 1977.

This study was conducted in 1969 to determine the effect of a major airline's modifications of aircraft flotation seat cushions governed by Federal Aviation Administration (FAA) Technical Standard Order (TSO) C72. Lengthening of the handstraps made it possible for a subject to insert his legs through the handstraps and thus don the cushion. Wearing the cushion in this manner produced an unstable condition with the potential for inversion of the body to a static upside-down attitude with the head and trunk submerged. On review of the data, the airline voluntarily reprocessed all flotation seat cushions. Previous evaluation and testing of aircraft flotation seat cushions are detailed in FAA Office of Aviation Medicine Report No. AM-66-13.

Use of Flotation Dummies in the Evaluation of Life Preserver Design, Survival and Flight Equipment Association (SAFE) Proceedings, 1969.

This report describes the design and construction of a flotation dummy for evaluation of life preservers, points out the inability of a conscious human subject to simulate unconsciousness in a water environment, and describes the need to use a human simulator to evaluate life preserver design because the test environment is hazardous for a human subject.

Buoyancy of Airline Life Jackets, Memorandum Report No. AAC-119-77-5(S), 1977.

This report describes the discrepancy in techniques for determining buoyancy of life preservers and how these techniques may ignore the Archimedes Principle in complying with FAA TSO-C13c, Airline Life Jackets.

Protection of Infants in Aircraft Ditching, Aerospace Medical Association (ASMA) Preprint, 1968.

This report describes a flotation device designed by the author and the considerations of buoyancy, self-righting, ventilation, and thermal protection incorporated in the design. Evaluation of this device is detailed in FAA Office of Aviation Medicine Report No. AM-71-37.

Color and Reflectivity of Sea-Survival Equipment as Related to Shark Attack, ASMA Preprint, 1971.

The effect of color and reflectivity of life jackets and flotation devices on the behavior of sharks in captivity and their natural habitat is described in this report.

Preliminary Results of Shark-Deterrent Testing of the Infant Flotation Device, Memorandum Report No. AAC-119-77-2(S), 1977.

Results of studies of the behavior of sharks with regard to the infant flotation device occupied by dummies and primates (baboons) are described in this report.

Survival Potential of Standard Diver's Wet Suits in Combination with the Beaufort Five-Man Liferaft, Memorandum Report No. AAC-119-77-6(S), 1977.

This 1972 evaluation was conducted in response to a proposal to use divers' wet suits in lieu of down-filled arctic clothing aboard FAA flight inspection aircraft operating in an arctic environment.

Evaluation of Safety and Survival Equipment Removed from an Aircraft Submerged at Lock Haven, Pennsylvania, During Hurricane Agnes, Memorandum Report No. AAC-119-76-1(S), 1976.

At the request of the FAA Office of Aviation Medicine, an evaluation of survival equipment removed from a submerged aircraft was conducted in the Civil Aeromedical Institute (CAMI) Protection and Survival Laboratory and survival tank. This evaluation was directed toward evaluating this equipment to assess its capability of withstanding adverse environmental rigors and not losing functional capability.

High-Density Loading of Multiple-Occupant Flotation Devices, SAFE Proceedings, 1972.

The effect of exposure of subjects to prolonged occupancy of a liferaft under high-density loading (2.45 ft^2 per occupant) is described in this report. In addition, open-water field evaluations of a DC-10 prototype slide/raft loaded with from 44 occupants (4.4 ft^2 per occupant) to 65 occupants (3.0 ft^2 per occupant) are described.

Evaluation of Aircraft Seat Cushion Flotation Characteristics, Memorandum Report No. AAC-119-77-12(S), 1977.

This report describes a brief exploratory evaluation of the flotation characteristics of an aircraft seat cushion and its ability to comply with the buoyancy requirements of FAA TSO-C72b, Individual Flotation Devices.

AIRCRAFT FLOTATION SEAT CUSHION EVALUATION

Ernest B. McFadden

I. Introduction.

An evaluation of five configurations of aircraft flotation seat cushions was conducted in the CAMI fresh-water survival tank. The primary parameters that were evaluated included adequacy of buoyancy, cushion cover integrity, and handstrap integrity. Tests were designed for dynamic evaluation of these factors; naive human subjects were used.

II. Methods.

Forty volunteers (27 males and 13 females) were recruited for this study. Cushions were assigned a designated letter of the alphabet (Table 1), and each subject was randomly assigned the use of a specific cushion as his or her primary flotation means in deep water.

TABLE 1. Description of Cushions

Cushion	Serial Number	Description
A	2841	Red/orange cover - two diagonal straps (880 coach)
B	2625	Olive/blue plaid cover - two diagonal straps (727 first class)
C	2630	Blue cover - two diagonal straps (727 coach)
D	2639	Olive/blue plaid cover - two diagonal straps and snap closure (707 first class)
E	2682	Blue cover - two short straps - Velcro and snap closure (707 coach)

Subjects were instructed to wear old clothing and swimsuits under trousers and dresses. Once the cushion entered the water upon initiation of the test, it was continually loaded with a human subject for a period of 8 hours with the exception of two brief periods each hour during which buoyancy was monitored and an evaluation of handstrap strength and integrity was conducted. The handstrap-strength evaluation was conducted each hour on the hour by a newly reporting subject, who jumped into the water feet first from a height of 5 feet while holding onto the cushion by the handstraps. Cushions were tested for buoyancy each hour on the half hour. To test the five cushions more rapidly, we fabricated a brass standard weight that exerted an effective weight of 14 lb when submerged and suspended from the cushion. The cushions were held in a polyethylene net of neutral buoyancy to allow rapid screening to determine if buoyancy decreased below the 14-lb minimum requirement. Any cushion that failed this test was subjected to a more thorough measurement of its exact buoyancy by use of a special Dillon model BTN1U101A electronic dynamometer and underwater load cell. The underwater load cell was secured to the bottom of the pool, and the cushion was pulled just below the surface of the water. The total buoyant force was then read directly from the master control unit on the surface. All testing was accomplished in fresh water at 85° F. The duration of each subject's use of a flotation cushion was limited to 1 hour in that it was not deemed practical for one subject to be exposed to 8 hours of immersion because of known physiological limitations. Subjects were allowed to use the device in whatever manner they considered most effective and comfortable. Wave action was not simulated.

III. Results and Discussion.

Characteristics of the 40 subjects used in these tests are shown in Table 2. A continuous tabulation of events during the evaluation of the five flotation seat cushions is shown in Tables 3 through 7. All cushions except cushion A (a CV-880 coach flotation cushion) exceeded the 14-lb minimum at all times during the 8-hour test. Cushion A dropped below the 14-lb minimum in 30 minutes or less. At one point, buoyancy increased to 14.5 lb but subsequently dropped to a low of 12.0 lb at the end of the 8-hour test. This phenomenon has been encountered in previous flotation-seat-cushion evaluations. It appears that under favorable circumstances water may drain from the open-cell-foam portion of the cushion, which is exposed above the water to the extent that air replaces the water with a resultant increase in buoyancy.

There was no failure of handstraps or their attachments as a result of eight individual 5-foot jump tests completed on each cushion. Covers on all cushions except cushion E (a B-707 coach cushion) became separated from the cushions at some point during the tests. Subjects were closely observed to insure that no subject made a specific effort to cause detachment of a cover from a cushion and that detachment, when it occurred, was a result of normal usage of the cushion as a flotation device.

It was noted that once a cover became detached from a cushion, the subject's efforts to replace the cover were not very effective because the water-soaked Velcro closures appeared to lose some of their cohesion. Subjects were, in general, unable to replace completely and secure the covers. As the test progressed, instances of cover detachment became so numerous that all instances could not be recorded and thus are not listed in Tables 3 through 7.

The five cushions used in these tests were allowed to air dry approximately 5 weeks before being utilized in another series of tests. These tests utilized five subjects who were considered to be representative of the smaller percentile individual in an adult population. All subjects were adult females.

Each subject was requested to report for the tests clothed in a swimsuit worn under a dress or other street clothing. The five cushions were arranged and evaluated in alphabetical order. The first subject was instructed to pick up cushion A and determine if she could with ease insert both legs through the handstraps. The height to which she could pull the cushion on her clothed body while standing erect was then recorded. This procedure was continued with cushions B, C, D, and E; no more than 30 seconds were allowed for each of the subjects to don a cushion.

The same procedure was repeated in water of sufficient depth that no assistance could be attained by contact with the bottom. During the water tests no time limit was enforced. It appeared, however, that donning was accomplished more rapidly and easily in the water. Physical characteristics of the subjects and results of the land and water cushion-donning tests are shown in Table 8. Following these tests, one strap of each of the five cushions was subjected to dynamic loading by a 194-lb male subject who dropped into the water from a height of 5 feet while holding the cushion overhead by one strap. No indications of handstrap failure were experienced. All female subjects reported that inserting their legs through the loops formed by the cushion straps was accomplished very easily in the water. In all instances donning was accomplished with the cushion floating with the straps suspended below the water surface and the subject assuming a supine position. Those cushions that were equipped with straps of sufficient length to allow the straps to be drawn up to the groin of the subject allowed the cushion to assume a final location on top of the subject's abdomen.

In this position a subject had to exert continuous and considerable effort with her hands in treading water to keep her head above the surface of the water. If the subject flexed at her waist and grasped the cushion with her hands, there was a tendency to rotate backward and thus submerge her head. Attempts by subjects wearing cushions to rotate forward so that a forward position (i.e., from vertical to prone) could be assumed were not successful. In addition, attempts to insert the legs in a cushion floating with the straps positioned on top of the cushion were unsuccessful because of the very unstable attitude that was produced. The task of inserting the legs into the straps in this position was also difficult.

IV. Summary and Conclusions.

A. All aircraft flotation seat cushions except the CV-880 coach cushion (cushion A) provided in excess of 14 lb of buoyancy for a period of 8 hours.

B. Covers of all cushions except that used on the B-707 coach (cushion E) became detached from the cushions during the 8-hour test period.

C. The handstraps on all cushions showed no indication of failure following eight subject drops into water with each cushion from a height of 5 feet while retaining the cushion with both straps and using both hands.

D. The handstraps on all cushions showed no indication of failure following one drop into water from a height of 5 feet while being retained by one strap and using one hand only.

E. Insertion of the legs into the straps of four of the five cushions evaluated (A, B, C, and D) was accomplished easily. In most instances the cushion straps could be positioned from midthigh to groin.

F. Insertion of the legs into the straps of cushion E could be accomplished with difficulty, but then only to positons below the knee. Once deployed in the water, however, this cushion became more immobilizing and more difficult to remove than cushions A, B, C, and D. Under these conditions the subjects frequently tended to become distressed and started thrashing about in the water in an attempt to free their feet.

G. Donning of the cushions by insertion of the legs placed subjects in a disadvantageous attitude because all positions that the subjects could assume or attempt to assume resulted in a final stable attitude with the cushion above the body. With the straps about the lower legs, subjects became distressed because their legs were immobilized and tended to lift their legs; as a result, the head and trunk of the individual would submerge. If the straps were elevated to the groin level with the cushion assuming a position over the abdomen, the feet and legs were less immobilized but there was still a tendency for the feet to be elevated out of the water and the head and trunk submerged.

TABLE 2. Characteristics of Subjects Used in Aircraft Flotation Cushion Evaluation

No.	Time	Age	Sex	Height (in)	Weight (lb)	Cushion
1	0830-0930	31	M	71.0	178	A
2	0930-1030	35	M	74.0	190	
3	1030-1130	42	M	67.5	140	
4	1130-1230	39	F	66.5	140	
5	1230-1330	30	M	75.0	140	
6	1330-1430	49	F	63.0	120	
7	1430-1530	37	M	67.0	153	
8	1530-1630	41	M	73.0	165	
9	0830-0930	31	M	73.0	155	B
10	0930-1030	38	F	61.5	87	
11	1030-1130	49	M	70.0	155	
12	1130-1230	40	F	66.5	158	
13	1230-1330	42	M	70.5	180	

TABLE 2 (Continued)

No.	Time	Age	Sex	Height (in)	Weight (lb)	Cushion
14	1330-1430	51	M	69.0	203	B
15	1430-1530	37	M	70.0	160	
16	1530-1630	45	M	70.5	205	
17	0830-0930	33	M	68.0	161	C
18	0930-1030	39	F	63.0	115	
19	1030-1130	26	F	65.0	128	
20	1130-1230	46	M	72.0	197	
21	1230-1330	40	M	71.5	153	
22	1330-1430	36	M	71.0	215	
23	1430-1530	45	F	65.0	130	
24	1530-1630	39	F	67.0	150	
25	0830-0930	31	M	68.0	140	D
26	0930-1030	41	F	64.0	123	

TABLE 2 (Continued)

No.	Time	Age	Sex	Height (in)	Weight (lb)	Cushion
27	1030-1130	43	M	70.0	165	D
28	1130-1230	51	F	64.0	150	
29	1230-1330	45	M	71.5	180	
30	1330-1430	35	M	68.0	155	
31	1430-1530	62	M	70.0	165	
32	1530-1630	54	F	72.0	128	
33	0830-0930	27	M	67.0	161	E
34	0930-1030	21	F	64.0	120	
35	1030-1130	40	M	71.5	172	
36	1130-1230	39	M	68.5	148	
37	1230-1330	25	M	73.0	195	
38	1330-1430	44	M	73.0	185	
39	1430-1530	27	F	66.0	128	
40	1530-1630	38	M	68.0	160	

TABLE 3. Evaluation of CV-880 Coach Flotation Cushion, TWA Part No. 87-2481 (Cushion A)

Subject	Sex	Time	Pounds Buoyancy Standard	Pounds Buoyancy Cell Load	Strap Integrity 5-Ft Drop	Cover Retention
1	M	0800 0830	< 14		Good	
2	M	0900 0930	< 14		Good	
3	M	1000 1030		13.5	Good	
4	F	1100 1130		13.8	Good	Cover half off--subject replaced
5	M	1200 1230	> 14	14.5	Good	Cover half off--subject replaced
6	F	1300 1330	< 14	13.5	Good	Cover one-fourth off--subject replaced
7	M	1400 1430	< 14	12.5	Good	
8	M	1500 Final	< 14 < 14	12.5 12.0	Good	

TABLE 4. Evaluation of B-727 First Class Flotation Cushion, TWA Part No. 87-2625 (Cushion B)

Subject	Sex	Time	Pounds Buoyancy Standard	Pounds Buoyancy Cell Load	Strap Integrity 5-Ft Drop	Cover Retention
9	M	0800 0830	> 14		Good	
10	F	0900 0930	> 14		Good	
11	M	1000 1030	> 14		Good	
12	F	1100 1130	> 14		Good	
13	M	1200 1230	> 14		Good	
14	M	1300 1330	> 14		Good	Cover half off--subject replaced
15	M	1400 1430	> 14		Good	Cover completely off--subject replaced
16	M	1500 Final		21.0	Good	

TABLE 5. Evaluation of B-727 Coach Flotation Cushion, TWA Part No. 87-2630 (Cushion C)

Subject	Sex	Time	Pounds Buoyancy Standard	Pounds Buoyancy Cell Load	Strap Integrity 5-Ft Drop	Cover Retention
17	M	0800 0830	> 14		Good	
18	F	0900 0930	> 14		Good	
19	F	1000 1030	> 14		Good	
20	M	1100 1130	> 14		Good	Cover completely off--subject replaced
21	M	1200 1230	> 14		Good	Cover completely off--subject replaced. Cover half off --subject replaced
22	M	1300 1330	> 14		Good	
23	F	1400 1430	> 14		Good	
24	F	1500 1530	> 14	16.0	Good	Cover half off--end test

TABLE 6. Evaluation of B-707 First Class Flotation Cushion, TWA Part No. 87-2639 (Cushion D)

Subject	Sex	Time	Pounds Buoyancy		Strap Integrity	Cover Retention
			Standard	Cell Load	5-Ft Drop	
25	M	0800 0830	> 14		Good	
26	F	0900 0930	> 14		Good	
27	M	1000 1030	> 14		Good	
28	F	1100 1130	> 14		Good	
29	M	1200 1230	> 14		Good	Cover partly off--subject replaced
30	M	1300 1330	> 14		Good	
31	M	1400 1430	> 14		Good	
32	F	1500 Final	> 14	19.0	Good	

TABLE 7. Evaluation of 707 Coach Flotation Cushion, TWA Part No. 87-2682 (Cushion E)

Subject	Sex	Time	Pounds Buoyancy Standard	Pounds Buoyancy Cell Load	Strap Integrity 5-Ft Drop	Cover Retention
33	M	0800 0830	> 14		Good	
34	F	0900 0930	> 14		Good	
35	M	1000 1030	> 14		Good	
36	M	1100 1130	> 14		Good	
37	M	1200 1230	> 14		Good	
38	M	1300 1330	> 14		Good	
39	F	1400 1430	> 14		Good	
40	M	1500 Final	> 14	21.0	Good	Good

TABLE 8. Approximate Location on the Body to Which Flotation Seat Cushion Straps Could be Donned and Positioned by Five Adult Female Subjects While Standing Erect (Land) and Supine (Water)

Subject: Age 25, Ht. 64½ in, Wt. 115 lb

Cushion A	Land	Both straps to midthigh level.
	Water	Both straps to groin level.
Cushion B	Land	Both straps to midthigh level.
	Water	Both straps to midthigh level.
Cushion C	Land	Both straps to above knee level.
	Water	Both straps to midthigh level.
Cushion D	Land	Both straps to knee level.
	Water	Both straps to knee level.
Cushion E	Land	One strap to ankle level.
	Water	Both straps to ankle level (difficult)

Subject: Age 26, Ht. 64 in, Wt. 125 lb

Cushion A	Land	Both straps to midthigh level.
	Water	Both straps to midthigh level.
Cushion B	Land	Both straps to midthigh level.
	Water	Both straps to midthigh level.
Cushion C	Land	Both straps to midthigh level.
	Water	Both straps to midthigh level.
Cushion D	Land	Both straps to knee level.
	Water	Both straps to midthigh level.
Cushion E	Land	Both straps to ankle level.
	Water	One strap to midcalf level.

TABLE 8 (Continued)

Subject: Age 51, Ht. 62 in, Wt. 96 lb

Cushion A -	Land	- Both straps to groin level.
	Water	- Both Straps to groin level.
Cushion B -	Land	- Both straps to groin level.
	Water	- Both straps to groin level.
Cushion C -	Land	- Both straps to groin level.
	Water	- Both straps to groin level.
Cushion D -	Land	- Both straps above knee level.
	Water	- Both straps to midthigh level.
Cushion E -	Land	- Both straps to knee level.
	Water	- One strap above knee level, other below knee level.

Subject: Age 42, Ht. 62½ in, Wt. 120 lb

Cushion A -	Land	- Both straps to midthigh level.
	Water	- Both straps to midthigh level.
Cushion B -	Land	- Both straps to midthigh level.
	Water	- Both straps to midthigh level.
Cushion C -	Land	- Both straps to midthigh level.
	Water	- Both straps to midthigh level.
Cushion D -	Land	- Both straps to midthigh level.
	Water	- Both straps to midthigh level.
Cushion E -	Land	- One strap to knee, one to ankle.
	Water	- Both straps to midcalf of leg.

Subject: Age 47, Ht. 58 3/4 in, Wt. 94 lb

Cushion A -	Land	- Both straps to groin level.
	Water	- Both straps to groin level.
Cushion B -	Land	- Both straps to groin level.
	Water	- Both straps to groin level.
Cushion C -	Land	- Both straps to midthigh level.
	Water	- Both straps to groin level.

TABLE 8 (Continued)

Cushion D -	Land	- Both straps to midthigh level
	Water	- Both straps to groin level.
Cushion E -	Land	- Both straps to calf level.
	Water	- One strap to midcalf, one to ankle level.

USE OF FLOTATION DUMMIES IN THE EVALUATION OF LIFE PRESERVER DESIGN

Ernest B. McFadden
Hiley F. Harrison

I. Introduction.

The capability of individual flotation devices to protect unconscious survivors is a major concern in many forms of water and air transportation. Regulatory agencies, private safety organizations, and manufacturers are promoting the development and use of improved life preservers for individuals engaged in boating and other water recreational activities.

Of equal concern is adequate and effective life preservers for workmen engaged in construction, repair, and inspection activities wherein incapacitation or unconsciousness may result from being struck by booms, cables, or other machinery and falling into the water from dams, bridges, docks, offshore drilling rigs, and barges or other work vessels. Similar mishaps may occur during aircraft ditching or crashes into water. An effective device to protect an unconscious survivor must include, in addition to adequate buoyancy, a rapid and immediate means of self-righting in order to place the survivor in such a position that breathing may continue without aspiration of water into the respiratory system.

Many previous evaluations have been based on the use of conscious human subjects to simulate the unconscious survivor. MacIntosh and Pask (1) in Great Britain have, through the use of anesthetized human subjects, demonstrated that survivors' behavior in water cannot be accurately simulated by conscious subjects who are understandably unable to repress basic and subtle reflexes involving body righting actions and respiratory activity. This paper describes the use of flotation dummies for experimental evaluation of various flotation device designs and the various parameters that influence their operational performance.

II. Methods.

The use of anesthetized subjects is a tedious and hazardous expedient. Pask and Christie (2) have recommended and pioneered the use of anthropomorphic dummies incorporating correct weight, buoyancy, and centers of gravity for the evaluation of flotation equipment design.

An improved anthropomorphic flotation dummy has been developed by the Sierra Engineering Company under a contract with the FAA Civil Aeromedical Institute (CAMI). The basic dummy design includes: (i) accurate weight and center of gravity of individual body segments, (ii) controlled variable segment buoyancy, (iii) controlled positive or negative total buoyancy and trim angles, and (iv) automatic recovery in the event of flotation device failure (Figure 1).

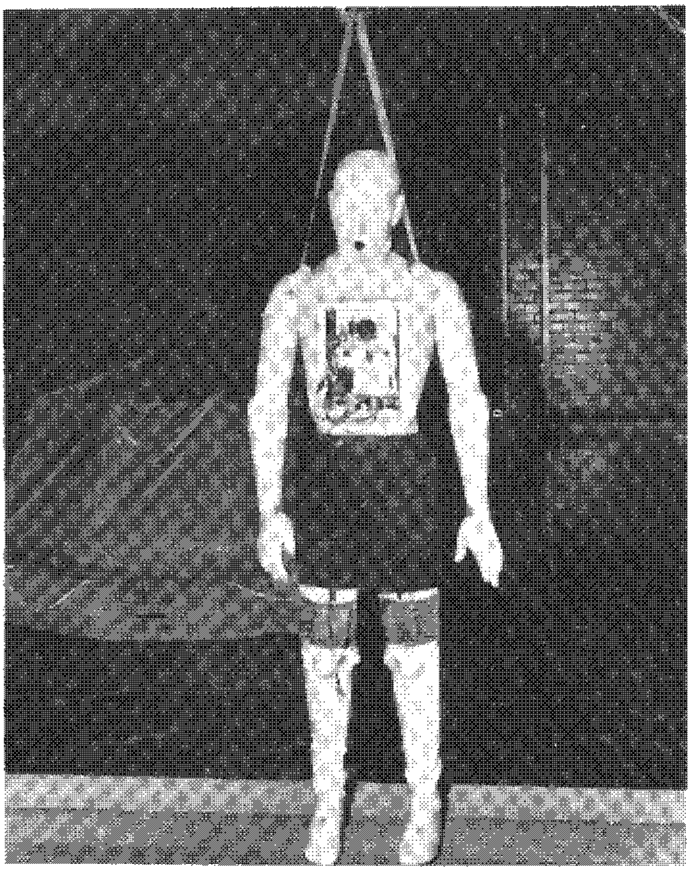

FIGURE 1. Flotation dummy with the chest plate removed and the telemetry system exposed. (Note automatic pressure-sensitive emergency recovery inflatables attached to the thighs just above the knees.)

An FM-FM telemetry system of the correct weight and center of gravity and incorporating miniaturized electronic components was designed at CAMI and installed in the dummy chest cavity in lieu of ballast to continuously measure data relative to body angle and respiratory system immersion. A simplified schematic diagram of this system is shown in Figures 2 and 3. A typical telemetry recording of the dummy dropped from a height of 4 feet at an angle of 68^{o} is shown in Figure 4. Note that telemetry transmission was not interrupted by total immersion of the dummy and its antenna.

To determine the protective efficiency of a life jacket design, one must know the buoyancy characteristics of human survivors. This information may then be duplicated in the dummy for evaluation of a device or devices throughout the range of buoyancy variability found in human subjects. For example, MacIntosh and Pask (1) became interested in what would happen to an anesthetized subject, breathing lightly and not supported by a life jacket, when placed in fresh water. In this instance, the subject sank promptly. In their words: "The trunk tends to sink a little after the legs, but the subject soon came to rest in a horizontal position on the floor of the tank."

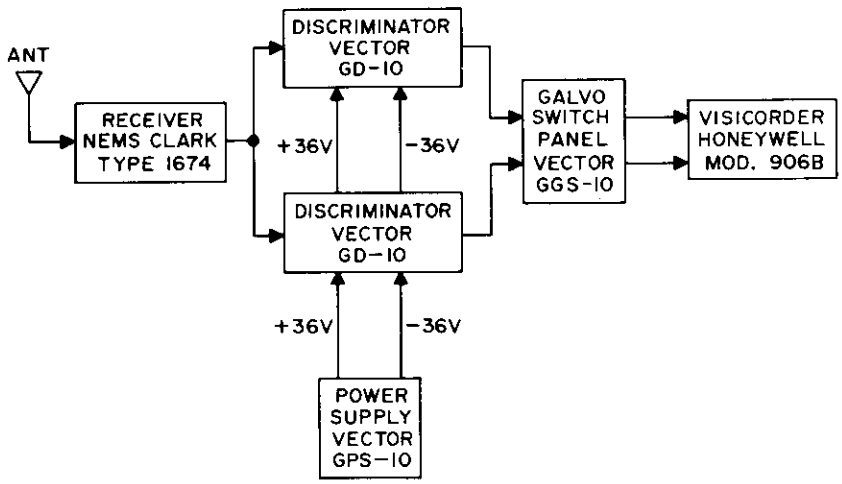

FIGURE 2. Simplified schematic of the flotation dummy telemetry receiving equipment.

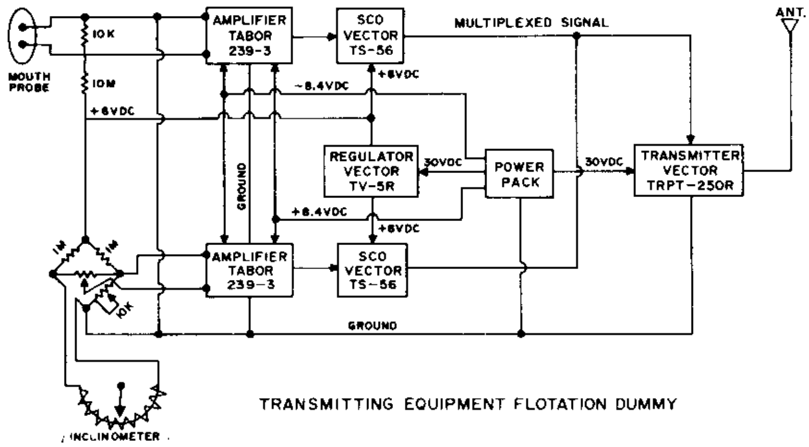

FIGURE 3. Simplified schematic of the flotation dummy telemetry transmitting equipment.

In a previous evaluation of a flotation device by the first author (3), the body densities of 12 male subjects varying from 57.8 to 101.6 kg in weight were obtained by the following technique:

First, the subject was carefully and accurately weighed in air. Following weighing, the subject was positioned in an underwater chair suspended from a balance. The water level was adjusted and a preliminary underwater weight of the subject was obtained. The subject then resubmerged, made a maximum exhalation, and turned the air control valve to the spirometer position. The subject made three maximum inhalations and exhalations and then turned the air control valve from the spirometer to snorkel position. After the final weight was obtained, the subject emerged from the water and a tare weight of the chair and breathing hose was obtained. Nitrogen analysis of the spirometer air was accomplished with a Med-Science Electronics Nitralyzer model 305AR. The procedure was repeated until the subject achieved complete exhalations as determined by a uniform recording on the spirometer drum. The residual volume (VR) and body density (D_1) were calculated as follows:

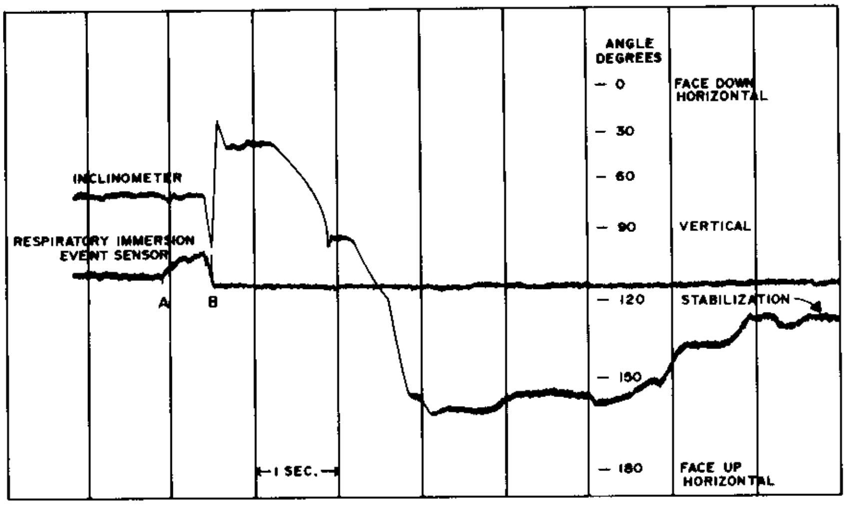

FIGURE 4. Example of telemetry recording. Drop Test Number 22. Dummy was nude, wearing a 22-pound-buoyancy plastic-foam, closed-cell workman's life jacket. Self-righting was rapid and stabilization was at approximately 130° (40° back from vertical) which is favorable for an unconscious survivor. The inclinometer is not critically damped and some overshoot may occur.
A - Respiratory system immersion.
B - Discontinuation of respiratory system immersion.

$$VR = V \frac{N_2}{N_1 - N_2} \times \frac{P_1 - P_2}{P_1 - 47} \times \frac{310}{273+T} - 55$$

VR = residual volume of lungs (cc).

V = volume of spirometer and hose (cc).

N_1 = fraction of nitrogen in end-expired air before rebreathing.

N_2 = fraction of nitrogen in end-expired air after rebreathing.

P_1 = barometric pressure (mmHg).

P_2 = partial pressure of water vapor in spirometer before rebreathing (mmHg).

T = temperature in spirometer before rebreathing (^oC).

47 = partial pressure of water in lungs (mmHg).

310 = absolute temperature in lungs (K).

55 = dead space in valve and mouthpiece (cc).

$$D_1 = \frac{M_1}{\frac{(M_1 - M_2)}{D_2} - V_R}$$

D_1 = body density.

M_1 = weight of subject in air (g).

M_2 = weight of subject under water (g).

D_2 = density of water at time of weighing.

V_R = residual volume of lungs (cc).

Following determination of the underwater body mass and residual lung volume, one has to assume that an unconscious subject breathing lightly will demonstrate a variation in buoyancy in proportion to his respiratory tidal volume. Buoyancy values as calculated at the end of inspiration and expiration are shown in Table 1.

Before evaluating a specific life preserver design, one must add or remove small quantities of air from various body segments of the dummy and establish the trim angle in order to duplicate the above values for human subjects. The total positive or negative body buoyancy of the flotation dummy is measured and verified by using underwater and surface load cells.

III. Results and Discussion.

In the evaluation of the capability of life preserver design to protect an unconscious survivor, the following parameters exert a marked influence upon their efficiency: initial entry attitude, clothing, preserver retention, preserver and survivor buoyancies, and body and appendange position following entry. In most life jacket designs the initial entry attitude profoundly affects the final stabilized position of the unconscious survivor.

TABLE 1. Human Body Density and Calculated Buoyancies of 12 Selected Male Subjects

Subj. No.	Body Density	Body Mass in Air (g)	Underwater Body Mass (g)	Residual Lung Vol. (cc)	Underwater Body Buoyancy (lb) A	B	C
1	1.0662	63,143	3,310	1,285	-4.47	-2.50	-0.96
2	1.0541	74,890	3,060	1,219	-4.06	-1.95	-0.41
3	1.0524	74,200	2,900	1,222	-3.70	-1.59	-0.05
4	1.0489	57,880	1,850	1,187	-1.46	+0.72	+2.26
5	1.0428	81,630	3,150	675	-5.46	-2.14	-0.60
6	1.0341	79,380	2,000	1,091	-2.01	+0.39	+1.93
7	1.0336	85,730	2,200	1,092	-2.44	-0.05	+1.49
8	1.0266	70,270	800	1,388	+1.30	+3.05	+4.59
9	1.0224	99,550	1,850	925	-2.04	+0.72	+2.26
10	1.0201	88,290	900	1,322	+0.93	+2.81	+4.35
11	1.0183	74,860	900	894	-0.01	+2.82	+4.36
12	1.0161	101,620	1,000	1,285	-0.63	+1.34	+2.88
					RANGE		
					+1.30-- -5.46	+3.05-- -2.50	+4.59-- -0.96

A Residual lung volume only (when including residual volume).
B Following normal expiration (when functional residual capacity included).
C Following normal inspiration (when tidal volume 700 cc or +1.54 lb included).

A. Entry Attitude. Free falls into water of from 4 to 8 feet, in which a clothed dummy is used to simulate an unconscious survivor contacting the water in the prone position (from 0° (horizontal) up to 90° (vertical)) normally require more righting capability than most life jacket designs can exert. If the dummy entering the water in the prone position emerges at or near 0° (horizontal), it will subsequently stabilize in the face-down position with the respiratory system submerged.

If, however, entry is in the supine position (90°-180°) and initial stabilization is near 180°, the dummy will assume a final face-up, horizontal position. In an unconscious survivor this position is also far from ideal, however, because the flaccid muscles of the neck may allow the head to tilt backward and submerge unless it is adequately supported. These findings are in close agreement with similar results obtained by MacIntosh and Pask (1) while using anesthetized human subjects. These two very stable positions frequently result from life preserver or flotation garment designs in which buoyancy is added to the lower trunk and/or legs. As pointed out by the above investigation, it may not be possible within the limitations of tolerable bulk to provide sufficient asymmetrical buoyancy to impose an adequate turning moment to overcome the keel-like action of the flaccid arms and legs that is experienced in the horizontal position.

B. Clothing. One of the most profound effects on the capability of a life jacket to affect rotation and self-righting was induced by variations in clothing. When the dummy was dropped from heights of from 4 to 8 feet in the prone position with entry attitudes of from 22° to 68°, various life jacket prototypes incorporating self-righting designs were incapable of effecting self-righting when the dummy was fully clothed. In these tests the dummy subsequently stabilized in the face-down, prone attitude with the respiratory system submerged. If, however, the dummy was clothed in a life jacket only and subjected to the same test conditions as when fully clothed, life jackets incorporating asymmetrical or other self-righting designs frequently effected prompt and effective rotation and self-righting. In drops of from 4 to 8 feet, air collected in the trousers of male clothing and frequently coalesced in the seat of the trousers, pockets, etc., in such a manner that lower trunk buoyancy was increased and the lower trunk elevated to the point that a face-down prone position was produced with little opportunity for self-righting. Variation in fabric porosity and clothing bulk as well as the weight of shoes, tool belts, or other equipment worn on the body have a marked influence on the efficiency of the life jacket.

C. Preserver Retention. Drops of from 4 to 8 feet with dummies and human subjects indicated that a number of life preserver retention systems were incapable of preventing extensive shifting of the jacket and relocation of buoyancy. In some tests, jackets were displaced upward and rotated anteriorly to the extent that the upper portion of the jacket, normally located in the area of the clavicle, was faced upward to a point level with the top of the head. In this position the unconscious survivor's respiratory system is partly or totally submerged. The extent of displacement appeared to be proportional to the height of the drops and the force developed at impact with the water. The lower edges of life jackets are frequently rounded or essentially flat and unrestrained at the lowest points; this arrangement allows a highly hydrodynamic force to develop during feet-first entry that has a tendency to pull the vest away from the survivor's body with subsequent jacket displacement. Possibly a study of the hydrodynamics of this area of the jacket could result in the development of a design that would instead exert a tendency to force the jacket toward the survivor's body and improve retention. Displacement of the jacket and redistribution of buoyancy may result in cancellation of the effectiveness of self-righting designs.

D. Preserver and Survivor Buoyancy. In considering the efficiency of a life jacket to provide adequate protection, one must keep in mind survivors of various body builds, density, and buoyancy. Table 1 describes the variation and range of buoyancy as measured by using 12 male subjects varying widely in body build and weight. Jackets designed to protect unconscious survivors require adequate buoyancy to elevate the survivor's head well above the surface of the water. Of equal importance is the distribution of buoyancy, which must be so located as to produce rapid self-righting and maintenance of a position in which the airways are not subject to water aspiration.

E. Body and Appendage Position. The position of the arms and legs of an unconscious survivor exert a marked influence on self-righting life jacket designs. MacIntosh and Pask (1) found that rotation and self-righting were most easily accomplished by a twisting motion when the unconscious subject is in a supine position of approximately 135° (45° back from vertical). The arms are closer to the body and the legs exert less resistance to rotation in this position as compared to the keel-like action of these appendages that exists when the body is in either the horizontal prone or the supine position.

In our human testing of several life jacket designs, we noted that the center of gravity of the jacketed subject supported in the 90° (vertical) position was very critical. The shift in body mass induced by voluntarily allowing the neck muscles to become flaccid and the head to fall forward was sufficient to produce a forward rotation and stabilization in the prone (face-down) position. Similarly, dropping the head backward resulted in similar rotation terminating in a supine (face-up) position with the head dropping back to the point that the face was frequently submerged. Unless properly supported, the head of an unconscious survivor may also tilt sideways to the extent that the airways may become partly submerged.

IV. Summary.

A flotation dummy designed to simulate the characteristics of an unconscious survivor is described. The relationship of this simulator to human subjects in which unconsciousness was induced by a volatile anesthetic is compared. A telemetry system incorporated into the dummy to provide basic data is also described. Various parameters and problems associated with life jacket design, as indicated by evaluations using the flotation dummy and human subjects, are discussed. It is recognized that factors other than those discussed in this paper, such as comfort, donning speed, materials, shelf and service life, etc., must also be considered in the design of a life jacket that will provide adequate protection under extremes of usage and environment.

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BUOYANCY OF AIRLINE LIFE JACKETS

Ernest B. McFadden
James M. Simpson

I. Introduction.

As a result of the ditching of an Overseas National Airlines DC-9-33F aircraft in the Caribbean Sea near St. Croix, Virgin Islands, on May 2, 1970, 23 of the 63 occupants lost their lives. Following this accident the National Transportation Safety Board recommended the Federal Aviation Administration (FAA) reexamine life jacket design requirements. As members of the human factors group investigating this accident, the authors noted numerous survivor complaints of the inadequacies of life jackets. Since buoyancy was described as being inadequate, a brief evaluation of life jacket buoyancy and methods employed for its measurement was initiated.

II. Methods.

A typical airline jacket--marked Model CP100(B) Serial No. 18224, Irvin Industries, Inc., Raleigh, N.C., and manufactured in July 1970 to FAA Technical Standard Order (TSO) C13c--Air Transport Association (ATA) Specification 801--was chosen as a test item. This jacket was removed from a B-747 aircraft at San Francisco, California, on July 30, 1971, as part of an investigation of a modification of the jacket retention strap stowage, which passengers complained increased the difficulty of their donning the jacket during an actual emergency.

To determine whether this jacket met the 23-lb design standard, a special brass weight exhibiting an underwater weight of 23 lb was machined. The weight was suspended from a polyethylene netting exhibiting neutral (i.e., 0) buoyancy, and the above CP-100 life preserver was inflated mechanically. The inflation system consisted of two MIL-C-601F carbon dioxide cylinders, each with a gross weight of 32.0 g and a net weight of 8 g as removed from the B-747 aircraft in San Francisco. The inflated jacket was then placed under the polyethylene netting, the brass weight was attached, and the jacket was placed in fresh water at 86° F.

A second method of determining buoyancy was employed in which the life jacket contained within the netting was connected to a calibrated Dillon underwater load cell and the tension was increased until the upper surface of the jacket was just below the surface of the water.

III. Results.

When the brass weight, exhibiting an underwater weight of 23 lb, was suspended from the inflated life jacket, the jacket promptly sank. When the

Dillon underwater load cell was utilized, 18.25 lb total buoyancy was recorded in fresh water at 86° F.

Paragraph 4.1.4 of TSO-C13c states: "The design of the life jacket shall be such that the buoyancy with mechanical inflation utilizing the Type I, 8 g, cylinder specified above shall be 23 lb (min) at 85° F." However, paragraph 4.3.4.1 states: "When mechanically inflated and placed in fresh water of normal temperature (70° F), the life jacket shall support a 20-lb steel weight without becoming submerged." Paragraph 4.1.4 is included under a design standard, whereas paragraph 4.3.4.1 is a qualification test.

There are several calculations significantly affecting buoyancy or the measurement of buoyancy that indicate many jackets may not be capable of meeting either of the above requirements.

A. Calculation of Buoyancy by Volumetric Displacement. A review of the specifications of one of the principal manufacturers of carbon dioxide cylinders (Knapp Monarch) indicates the MIL-C-601B, Type I, and the MIL-C-601F, Type I, cylinders (as used in the CP-100 jacket) expel 0.16 ft^3 of gaseous carbon dioxide per cylinder at 70° F and 14.7 psia. Each cylinder would produce a quantity of free gas sufficient to provide 9.97 lb of buoyancy or 19.94 lb total at 70° F in fresh water. In salt water the two cylinders would provide a total of 20.48 lb buoyancy at 60° F.

B. Calculation of Buoyancy Based on Molecular Weight. Instead of calculations based on the volumetric specification above, the buoyancy may also be calculated from the molecular weight of carbon dioxide. The two cylinders containing 8 g of liquified carbon dioxide produce a total of 19.86 lb of fresh water buoyancy at 86° F and 14.7 psia. If there is any pressure buildup in the jacket, the buoyancy is reduced even further. If the pressure within the jacket reaches 1.0 psig in fresh water, the buoyancy is reduced to 18.60 lb at 86° F. It is not uncommon for the pressure in the jacket to approximate 2.0 psig, and paragraph 4.3.3.2 of TSO-C13c requires that each compartment be capable of withstanding 10 psig without failure. Due to contraction of the gas, buoyancy would be reduced even further at the lower water temperatures that prevail at sea.

IV. Discussion.

Assuming a life jacket is properly donned and one ignores temperature considerations, the life saving effectiveness of a life jacket is largely dependent on design characteristics associated with buoyancy and stability and the resultant attitude of the survivor's body. These design characteristics must be so integrated that the survivor's airways are positioned sufficiently above the surface of the water to prevent inspiration of water and drowning. Most life jacket designs, therefore, employ some means of head support in an attempt to prevent submersion of the nose and mouth. Buoyant compartments are often symmetrically or asymmetrically distributed with the intent of providing a design capable of righting the survivor in a stable attitude favorable to survival.

If protection of an incapacitated or unconscious survivor is considered, then design parameters become even more complex. MacIntosh and Pask (1) in Great Britain have demonstrated through the use of anesthetized human subjects that the unconscious survivor's behavior in water cannot be accurately simulated by conscious subjects. The conscious subject is incapable of repressing basic and subtle reflexes involving righting actions and respiration. An effective design to protect an unconscious survivor must include, in addition to adequate buoyancy, a rapid and immediate means of self-righting to place the survivor in a position that breathing may continue. Studies conducted in our laboratory by using a specially constructed flotation dummy (2) to simulate the unconscious survivor indicated the following factors to be important considerations in life jackets designed to protect the incapacitated or unconscious survivor:

A. Initial attitude on entry into the water.
B. Life jacket retention system reliability.
C. Total life jacket and survivor buoyancy.
D. Distribution of buoyancy.
E. Clothing: type, weight, fabric weave, shoes, boots, tool belts, or other accessories.
F. Body and appendage position following entry into the water.
G. Symmetrical versus asymmetrical buoyant compartments.
H. Sea state.

V. Conclusion.

The Archimedes Principle seems to be frequently ignored. The qualification test specifies the life jacket shall support a 20-lb steel weight without being submerged. In practice, it is almost impossible to acquire sufficient stability to lay a weight on the upper surface of a floating life jacket without some or all of the weight being submerged. A 20-lb steel weight (99% Fe, 1% C), if submerged (for example, suspended from the jacket), weighs only 17.66 lb in fresh water at 70° F and, therefore, applies a load to the jacket of 17.66 lb instead of 20 lb.

All too frequently life jacket standards fail to define buoyancy and allow testing procedures that ignore basic physical laws. For example, the Archimedes Principle states that an object, when submerged in a liquid (in this case, water), is buoyed up by a force equal to the weight of the liquid displaced. Thus, heavy metal weights of lead, brass, or steel exert a lesser force and weigh less when submerged than when weighed in air. When weights are used in the testing of life jackets, and any portion of a weight is submerged, appropriate corrections must be made.

An increase in pressure within an inflatable jacket will also produce a reduction of buoyancy. When a specific volume of gas at ambient pressure temperature (STP) is released into an inflatable jacket, water displacement and thus buoyancy are reduced as the pressure (confinement) of the gas is increased.

In January 1976, the Society of Automotive Engineers (SAE) S-9 Cabin Safety Provisions Committee issued Aerospace Recommended Practice (ARP) 1354, Individual Inflatable Life Preservers, which includes the increase of adult or adult/child combination life jacket buoyancy to 35 lb, the improvement of self-righting capability, and the use of absolute buoyancy in the testing and evaluation of life jackets. Life jacket test methods allowed in ATA Specification 801 and TSO-C13c do not insure that the specified design goal has been achieved. Moreover, it appears impossible to achieve the design buoyancy solely through the volume of free gaseous CO_2 provided by two 8-g cylinders. Revisions to this document, which are currently under consideration, may rectify this inconsistency.

Effective life jacket design must also include consideration of anatomical, physiological, and biophysical characteristics of the human body. These include body composition, distribution of body fat, sex, age, and the effects of immersion on respiration and hormonal control (3).

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PROTECTION OF INFANTS IN AIRCRAFT DITCHING

Ernest B. McFadden
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D. L. Wolfensparger

I. Introduction.

The protection of infants and small children involved in an aircraft ditching at sea poses a difficult problem. Tests of children's life preservers indicate they provide adequate flotation and stability in the environment of still water of a test pool. However, simple movements, such as holding the hands above the head, are sufficient to transfer the center of gravity to the extent that the child may rotate and the face become submerged. If the water is disturbed and a choppy surface created, representative of a relatively calm sea, the child life preserver provides little or no protection of the respiratory system of the infant or small child. Immersion of an infant or child in cold water presents another basic problem. Water has a specific heat--approximately 1,000 times that of air--so that for a given increase in temperature, each cubic centimeter of water contacting the skin is capable of taking up a thousand times more heat from the body than is a comparable volume of air (1). Also, the thermal conductivity of water is approximately 25 times greater than that of air (1).

Infants and small children exhibit a surface area per unit of body mass two to three times that of an adult (2). In addition, the total body weight of infants ranges from one-twentieth to one-fifth that of an adult with a resultant reduction in total body specific heat. Survival times of infants and children immersed in cold water are therefore drastically reduced because of the larger surface area per unit of body mass and the reduced quantity of heat initially available to maintain body core temperature.

An airline captain who had been involved in two ditchings of commercial transport aircraft (Lisbon, Portugal, and San Juan, Puerto Rico) stated in his recommendations following the hearing of the latter ditching that he saw no reason to have expected any loss of life with the two exceptions that did occur: failure of life jackets to inflate and loss of six infants.

It is the purpose of this paper to examine the requirements of infant and small-child flotation devices and describe a flotation design that may lead to increased survival of this segment of the passenger population.

II. Methods.

In the consideration of design requirements for an infant and small-child flotation device, the following primary factors were considered: (i) buoyancy, stability, and self-righting, (ii) thermal protection (cold water immersion), (iii) ventilation, (iv) impact protection, and (v) predatory marine life.

One of the most critical characteristics of any flotation device is adequate buoyancy and stability. In the case of an infant flotation device, reliable self-righting is also essential. Children's life preservers, infant survival cots, and similar devices we have evaluated have not met all these requirements. Data relative to the centers of gravity of small children were obtained from the study by Swearingen et al. (3) and from similar unpublished data relative to infants. This information was utilized in arriving at the basic concept of an infant flotation design. An experimental prototype device incorporating this design concept was fabricated by the Life Support Systems Division, U. S. Divers Company (Figure 1).

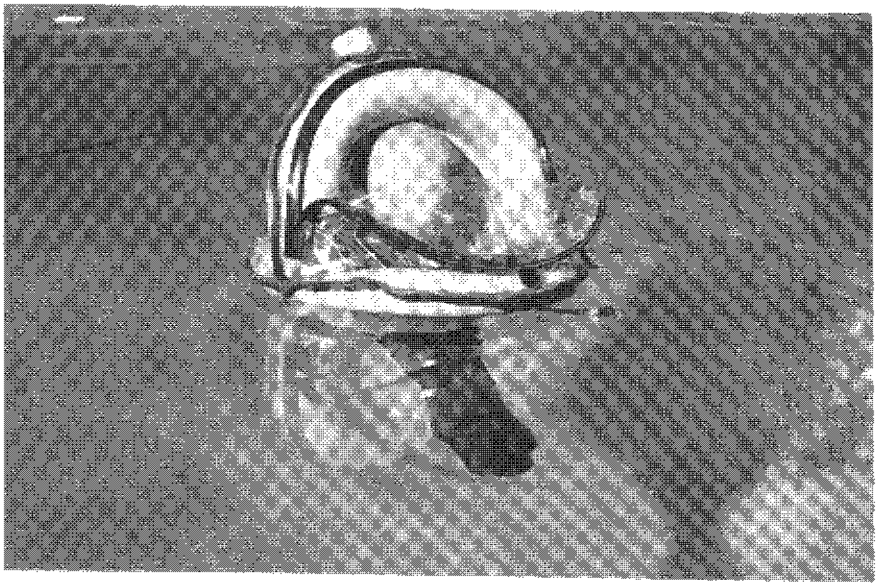

FIGURE 1. Infant and child flotation device occupied by an anthropometric dummy representative of a 3-year-old male.

This device consists of two separate buoyant flotation compartments, each inflated by separate 57-g carbon dioxide cylinders. An oral means of inflation is also provided. The lower portion of the device is constructed of ¼-inch nylon-lined black neoprene foam and equipped with a waterproof zipper. A 3/4-inch-diameter snorkel is mounted in the aft plastic window, and two nonreturn valves are mounted near the upper surface of the buoyant ring. The device is equipped with a light nylon strap and snap for connection to the adult life preserver. Total weight of the device is 4½ pounds.

The immersed portion of the device, composed of neoprene foam, was designed to provide a minimum of surface area and avoid the well-known problem of "insulation of small cylinders" (1).

III. Results and Discussion.

Field tests were carried out by using an anthropomorphic dummy representative of a 3-year-old child. Since smaller infant and child dummies were not available, dolls were obtained and modified so as to exhibit the body weight and centers of gravity of children 2½ years to 4 months old. Tests under wind and wave conditions indicated excellent stability. Water impact tests were carried out from cliffs 13 to 21 feet high. The device containing the dummy was released in the inverted position. The center of gravity is such that self-righting normally occurs before the device enters the water. The stability and self-righting characteristics of the flotation device were recorded by utilizing surface and underwater motion picture photography during these evaluations.

The thermal conductivity of neoprene foam is 4.6 $kcal/m^2/h/^oC/$ per cm thickness (1). Using the 3-year-old anthropomorphic dummy and measuring the surface area immersed, one may crudely estimate the heat loss due to Newtonian cooling at 3 kcal per ^oC. The total basal heat productivity of a 2½-year-old child approximates 25 kcal. Unfortunately, there is no information in the literature relative to the CLO value of the skin and subcutaneous tissue of infants and small children. In addition, the clothing worn by infants and small children is not predictable. The body above the waist is not subject to immersion, but it is subject to loss of heat by convection, conduction, evaporation, and radiation and is unaccounted for in the previous calculation. These unknown parameters plus the "greenhouse effect" of the transparent enclosure make accurate calculation of the heat loss practically impossible.

With the buoyant compartments deflated, the device becomes a bassinet to provide some degree of environmental protection as shown in Figure 2.

Ventilation is provided by compression and relaxation due to wave action as shown in Figure 3. In still water, a condition that is extremely rare at sea, the front closure may be partly opened, if desired, or it may be completely opened.

The two buoyant flotation compartments may provide some degree of protection to the trunk, arms, and head of an infant or small child during impact of a premeditated ditching.

The infant flotation device is similar in configuration to the Johnson shark attack deterrent but is much smaller and does not conceal the human form (4,5). The immersed portion of the infant flotation device is of a

FIGURE 2. Potential utilization of the infant and child flotation device: A--in water; B and C--environmental protective bassinet in a life-raft or on land.

black, nonreflective material that appears to have a deterrent effect relative to shark attack (4,5). In addition, like the Johnson shark device, human odors, vomitus, and excreta, which might attract sharks, are retained within the device.

IV. Summary.

A flotation device concept for infants and small children is described. One experimental prototype has been fabricated. Tests of this device have indicated a requirement for a larger diameter snorkel device and relocation of the carbon dioxide and oral inflation devices in future prototypes. Stability and self-righting characteristics have been demonstrated. Additional studies of the thermal, ventilatory, impact, and shark-deterrent characteristics of these design prototypes are required.

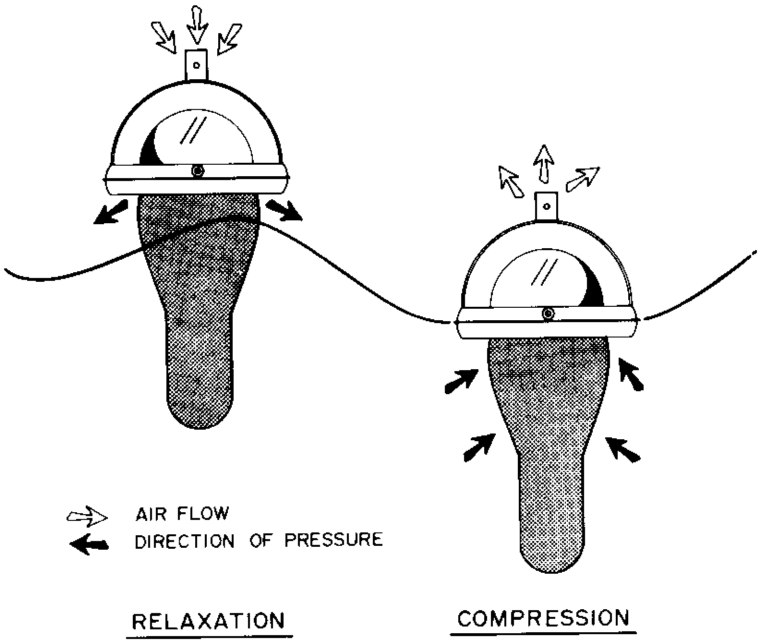

FIGURE 3. Diagram illustrating flotation device ventilatory flow due to alternate compression and relaxation induced by wave action.

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PRELIMINARY RESULTS OF SHARK-DETERRENT TESTING OF THE INFANT FLOTATION DEVICE

Ernest B. McFadden

I. Introduction.

Adult and child life preservers fail to provide adequate protection when worn by infants or small children exposed to high seas and an adverse thermal environment. To provide increased protection, the author designed a simple, lightweight, life-support, infant flotation device. The life-support capability of this device has been previously described (1,2). This report describes the behavior of predatory marine life--in this instance, sharks--toward the infant flotation devices and life jackets (3).

II. Behavior of Sharks in Captivity

The first series of tests of the shark-attack-deterrent capabilities of the infant flotation device (IFD) was carried out at the Mote Marine Laboratories shark pens at Siesta Key, Florida. Captive coastal and bottom-feeding sharks were used. Species included the brown shark (Carcharhinus milberti), tiger shark (Galeocerdo cuvieri), and bull shark (Carcharhinus leucas). These species of sharks are known to be dangerous to man, but some of them had been captured recently and had not yet begun to feed. The 11-foot tiger shark's behavior was not normal; even though she had been in captivity for some time, she had rammed the sides of the pen to the point that physical injury had occurred. The bull sharks had been captured recently and had not adjusted to captivity. The brown sharks, even after several months of captivity, refused to feed. Despite these qualifications, several statements can be made concerning this series of experiments.

A. The IFD was markedly less attractive to sharks than was an anthropometric doll in a standard life vest.

B. The IFD neither strongly attracted nor repelled the sharks in these experiments.

C. No differences in shark activity were observed when black or red IFD's were employed, both of which produced low reflectivity under water.

D. The sharks used in the testing program were noticeably more active and aggressive at night, especially toward the doll equipped with a life vest only.

E. When a tranquilized (8 mg/kg Sernalyn) adolescent female baboon was placed in the IFD and exposed to attack, the sharks' initial reaction was to congregate at the opposite side of the pool and avoid the baboon. They subsequently approached the device and baboon with considerable caution. This behavior agrees with Dr. Baldridge's observations (personal communication) with hairy mammals (laboratory rats); he found that sharks would not attack these rodents while the rodents were swimming. However, with the IFD enclosing the baboon, the hair was not visually apparent. It would appear that the strange odor or movements of the animal may have accounted for the unusual behavior of the sharks.

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COLOR AND REFLECTIVITY OF SEA-SURVIVAL EQUIPMENT AS RELATED TO SHARK ATTACK

Ernest B. McFadden
Scott Johnson

I. Introduction.

The development of sea-survival equipment such as liferafts, lifevests, and canopies has emphasized the requirements for a high degree of conspicuity through the use of materials of a bright hue, contrast, and reflectivity to aid in the search and rescue of aircraft ditching survivors. Even with the event of more sophisticated signaling devices allowing long-range location and detection, the continuous visual acquisition desired within the immediate recovery area is influenced by the conspicuity of the survivors and their equipment. Conversely, military missions may require minimization of contrast and conspicuity to avoid detection by the enemy.

With respect to factors influencing shark behavior, there is mounting evidence that the degree of brightness and conspicuity as detected by the visual sense of sharks may promote or passively deter attack.

Gilbert (1) in 1962 stated that the sense of sight is the research target of what appears to be the only effective, although not universally practicable, shark repellent.

Adult and child life preservers fail to provide adequate protective capability when worn by infants or small children exposed to high seas and an adverse thermal environment. To provide increased protection, scientists at the Civil Aeromedical Institute designed a simple lightweight life-support infant flotation device. It has been described previously (2,3).

Life-support-design criteria have been tested and evaluated (2,3), with the exception of those factors influencing shark attack. This paper is addressed to the factor of shark attack on this device and other flotation means.

Some of the concepts of the Johnson Shark Screen were inherent in the infant flotation device design. Previous evaluations of the Johnson Shark Screen indicated that the darker, nonreflective bags of large size and indefinite shape that conceal the human form appear to deter shark attack (4,5). However, the infant flotation device differs in that it is much smaller and, because of thermal and ventilatory requirements, does not completely conceal the human form.

II. Methods.

Two prototype infant flotation devices were fabricated, one incorporating a black, nonreflective immersed surface and the other a brightly colored immersed surface. The immersed portion of the brightly colored device consisted of a lower tapered neoprene foam bag of a bright red color supported by a bright yellow inflatable ring. In a previous study (3,6), these two prototypes, occupied by an anthropomorphic dummy or primate, were repeatedly exposed to captive coastal and bottom-feeding sharks in the Mote Marine Laboratory shark pens, Siesta Key, Florida. As a control, a typically clothed anthropomorphic child dummy equipped with a standard yellow airline life preserver was simultaneously exposed. Species used in these experiments included brown sharks (Carcharhinus milberti), tiger sharks (Galeocerdo cuvieri), and bull sharks (Carcharhinus leucas), all of which are known to be dangerous to man. This study indicated those devices should also be exposed to sharks in their natural habitat.

In cooperation with the Naval Undersea Research and Development Center, a second series of evaluations of the infant flotation device, consisting of exposing these devices and controls to pelagic sharks in their natural habitat, was carried out by using the Center's underwater observatory vessel, the See Sea. This ingenious and valuable research tool is equipped with a retractable underwater transparent capsule accommodating two observers in a shirt sleeve environment and allowing nearly 360° observation and photography. In this series of tests, sharks were attracted to an area by introducing small quantities of a dilute solution of homogenized bonito. The test items simultaneously introduced into the water consisted of a black, nonreflective infant flotation device; a child dummy wearing a yellow lifevest; a bright red infant flotation device; and a child dummy wearing a yellow lifevest spray painted a dull black. Each of the devices was tethered to the vessel and an attempt was made to maintain consistent separation and relative position.

III. Results.

The captive brown, tiger, and bull sharks utilized in the tests at the Mote Marine Laboratories, even though having been maintained in captivity in some instances for several months, refused to feed. However, on the basis of interest as determined by the frequency of bumps and passes, it was concluded that the infant flotation device was markedly less attractive to sharks than an anthropomorphic dummy in a standard lifevest (6).

Exposing these devices to sharks in their natural environment revealed a considerably more aggressive behavior. The standard yellow lifevest occupied by an anthropomorphic child dummy was repeatedly and consistently attacked on the surface by blue sharks (Prionace glauca). In most instances the legs, arms, and body of the child dummy were not attacked by blue sharks until after the vest was attacked and deflated and the dummy had sunk below the surface. Frequently, the attack on the yellow vest continued even after the dummy had sunk. Some dozen yellow life preservers were destroyed or damaged beyond repair in these attacks.

The yellow ring on the red infant flotation device was bitten twice by blue sharks, once near the shiny chrome-plated carbon dioxide cylinder. During these attacks, the lower red portion of the device incurred one bite. In one instance, the blue sharks were stimulated to a state of excitement (olfactory-induced frenzy-biting of each other, etc.) by accidental introduction of a large quantity of concentrated bonito homogenate. The lower portion of the black infant flotation device, located in the middle of this melee, was apparently indistinguishable from other combatants in the immediate area and incurred its only bite during the tests. One other bite occurred on the flotation ring near the shiny carbon dioxide cylinder. The cylinders on the black infant flotation device and lifevest were subsequently painted dull black. No further attacks occurred on these devices.

Mako sharks (Isurus oxyrinchus) appeared occasionally in the area but circled at the limits of visibility (50-100 feet). No more than three were observed in the area at any one time, whereas as many as 45 blue sharks collected in the area without fear of the vessel or the underwater observatory. Without exhibiting the preliminary surface behavior characteristic of the blue sharks, mako sharks made high-speed attacks from below, baring their teeth and snapping their jaws just prior to contact with their target. Three principal attacks by mako sharks were made on the anthropomorphic dummy equipped with a yellow vest. In one instance, the arm was torn from the dummy and appeared to be ingested. Mako sharks did not attack either of the infant flotation devices or the child dummy equipped with a black lifevest but in each instance selected the anthropomorphic dummy wearing a standard yellow lifevest.

The anatomy of the shark's eye indicates that reflectivity and contrast play a major role in its feeding behavior. Cones have been demonstrated in the retinas of only a few species of sharks, and they are outnumbered by rods as much as 150 to 1. Since the retinas of the majority of sharks are cone free and lack both area centralis and fovea (7), it may be concluded that sharks are incapable of perceiving color and have a vision of low acuity. On the other hand, rods are very abundant and in multiples they convey their impulses to a single bipolar or ganglion cell and thus produce summation of impulses (7). This results in an eye with great sensitivity that, although low in visual acuity, can readily detect an object or movement against a contrasting background in the dimmest of light. This high degree of sensitivity is further enhanced by the tapetum lucidum, a mirror-like layer underlying the retina and consisting of guanine crystals, which reflects incoming light back through the retina and restimulates the rods. Other special structures and mechanisms aid in light and dark adaptation (1,7).

There are two additional major sensory systems. The lateralis system consists of fine canals lying just beneath the skin on both sides of the body. These canals are lined with clusters of neuromasts from which hair-like structures extend into the fluid-filled canal. This very sensitive vibration-sensing system appears to be capable of detecting vibrations or disturbances, such as the splashing of injured fish, at considerable distances--possibly from many miles away, as in the case of sea disasters when water impact or explosions are involved. Olfaction is facilitated by water continuously passing through the nostrils and olfactory sacs, which exhibit a very large surface area and enable the shark to detect an odorous substance in concentrations as low as one part in several million. It is thought that the vibration and olfactory senses are of primary value for sensing and locating prey from a considerable distance, whereas once the prey is located, the visual sense plays a major role in the actual attack.

Conspicuity for reasons of search and rescue is of prime importance, and it is not recommended that all life preservers be manufactured of a nonreflective black material. However, methods of presenting a less attractive target to the shark and simultaneously presenting a contrasting, conspicuous image to surface search and rescue personnel should be pursued. Large inflatable equipment is not immune to attack. In addition to having a measured bite strength in excess of 18 metric tons (1), some sharks are capable of protruding the jaw and attacking attractive inanimate objects with a slashing motion of the head.

IV. Conclusion.

Methods for rendering lifevests and reversible liferafts less conspicuous and attractive visual targets for shark attack should be explored. Highly reflective and attractive hardware, such as chrome-plated carbon dioxide inflation cylinders, buckles, and snaps normally found on lifevests, should be of a black, nonreflective material. The submerged portion of liferafts or slide/rafts considered nonreversible should be of a black, nonreflective material.

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SURVIVAL POTENTIAL OF STANDARD DIVER'S WET SUITS IN COMBINATION WITH THE BEAUFORT 5-MAN LIFERAFT

Ernest B. McFadden
Don deSteiguer

I. Introduction.

Brief testing was conducted in arctic conditions to evaluate the survival potential of standard diver's wet suits in combination with that protection provided by the Beaufort five-man liferaft. This evaluation was conducted in response to a proposal to utilize diver's wet suits aboard FAA flight inspection aircraft in lieu of down-filled arctic clothing.

The cold chamber facilities and associated personnel of the Aviation Physiology Laboratory were utilized for this purpose. Test conditions established were -20° F and a wind velocity of 10 mi/h, giving a wind chill index of -46° F. The Beaufort raft was positioned with the canopy access at 90° to the wind and with the canopy snaps downwind. In this position, the canopy inflation tube was parallel with the wind direction. The raft was equipped with a standard hand pump; a standard 5-in, 3.5-oz survival candle; a speaker system for communication; and limited leads for thermocouple monitoring.

The three participating subjects were middle-aged males with considerable experience and knowledge of primitive camping, cold weather conditions, cold weather clothing and equipment, and the physiological effects of cold exposure. With these subjects, a range of physical stature was achieved: 6 ft 1 in, 220 lb; 6 ft, 190 lb, and 5 ft 8 in, 140 lb. Standard diver's wet suits of 3/16-in unicellular neoprene (Parkway Fabricators, South Amboy, New Jersey), consisting of hoods, jackets, pants, booties, and gloves (five-finger), were worn. Under the wet suits, standard cotton tee shirts, shorts, and socks were worn. Standard military cotton flight suits were worn over the wet suits.

II. Results.

The donning of diver's wet suits is, and was, a time-consuming process during which a significant amount of moisture accumulates within the suit. The donning of flight suits over the wet suits was difficult (over the shoulders) and required assistance. This dressing process would have been impossible for anyone who had sustained any degree of injury to the arms, shoulders, neck, or back.

On entering the cold chamber, subjects were briefly delayed (2 min) prior to entering the raft because the wind entangled cables and cords at the canopy entrance. During this brief delay, it became obvious that the clothing worn would not provide sufficient protection beyond a few minutes under these conditions. After the subjects entered the raft, thermocouples were connected and the candle was lighted. All subjects experienced cold feet within 15 min and noticed the effects of accumulated moisture within the wet suits. As the raft began to cold soak, the amount of surface contact between the individual and the raft became critical. With the three subjects involved, considerable crowding was experienced and efforts to reduce surface contact were generally ineffective. The first subject to experience body shivering (within 1 hr) was the largest, and he had direct shoulder contact with the canopy. The chest temperature of this subject dropped by 11.2° F to 87.4° F within 50 min and he was withdrawn from the test at 1 h 10 min. With two subjects in the raft, it was possible to keep surface contact with the canopy to a minimum; however, body shivering was being experienced by the second subject and finger temperature of the third had dropped to 49.5° F. As a result, the trial was discontinued at 90 min. Following the trial, all subjects experienced considerable pain in the hands and feet, an indication that a reasonable maximum duration to these conditions was obtained. At the time of termination, the air temperature within the canopy was 5° F and the surface temperature of the inflated floor was -4° F. A significant wind test of the raft structure was not possible as the maximum wind velocity obtainable was 27 mi/h.

III. Conclusions and Recommendations.

The use of a 3/16-in-neoprene standard diver's wet suit as the primary protective clothing for arctic survival conditions cannot be recommended for the following reasons: (i) the suit does not provide sufficient insulation for even mild arctic conditions; (ii) the suit, to be effective as a water survival garment, must be closely fitted to each individual; (iii) the time required for donning the wet suit precludes its employment following the onset of an emergency; (iv) in the event of many types of injuries associated with emergency landings, the donning of wet suits would be impossible; (v) the close fit required for the wet suit to be effective in water necessitates the discarding of almost all clothing the individual would be wearing if the wet suit were to be worn for dry cold conditions; (vi) the rapid accumulation of moisture within the wet suit, when utilized as a dry cold garment, leads to rapid chilling and early frostbite; and (vii) the closed-cell structure prevents compression packing of the garment, and neoprene fabric will crack when packed for extended intervals with sharp folds or creases. The concept of brief survival protection coupled with rapid rescue, while applicable to helicopters that operate with limited ranges, should not be applied to aircraft that operate over wide expanses and in potential weather conditions that would prevent quick location and/or rescue.

The poor insulation properties of wet suits as applied to dry cold conditions are well documented in the literature. Tolerance times with 3/16-in-neoprene wet suits to dry cold exposure are reported by Santamaria et al. (1) to be 100 min ± 20 for 20° F, 75 min ± 10 for 0° F, and 45 to 55 min for -40° F. The problem of moisture collection within the wet suit when worn as a dry garment was stressed by the authors. Mazzone (2) reports the limit of useful activity to be 60 min for subjects wearing this suit during dry cold exposures to -20° F and a wind velocity of 5 mi/h (wind chill index of -25° F). These conditions tested are mild compared to hard arctic survival conditions that might be compounded with injuries and subsequent limited body movement. The insulating value of the 3/16-in-neoprene wet suit is reported by Goldman _et al_. (3) to be only 1.32 clo in air, a value not far removed from that of a man's wool business suit. These data support the conclusions drawn from our own experience and testing; i.e., the diver's wet suit does not even approach the necessary insulating capacity required for arctic survival conditions.

The Beaufort five-man raft with self-erecting canopy and inflated floor did provide significant additional protection. A short period of thermal protection was afforded, approximately 2 h, while the raft was cold soaking. Once the raft had cold soaked, the major protection provided was against the wind component of the wind chill index. In conditions where the wind velocity is 5 mi/h or less, the application of emergency heat sources within the canopy, such as candles, will be more effective; however, surface contact with the deck will still be a critical factor.

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FIGURE 1. Subjects in wet suits with thermocouple leads taped in position.

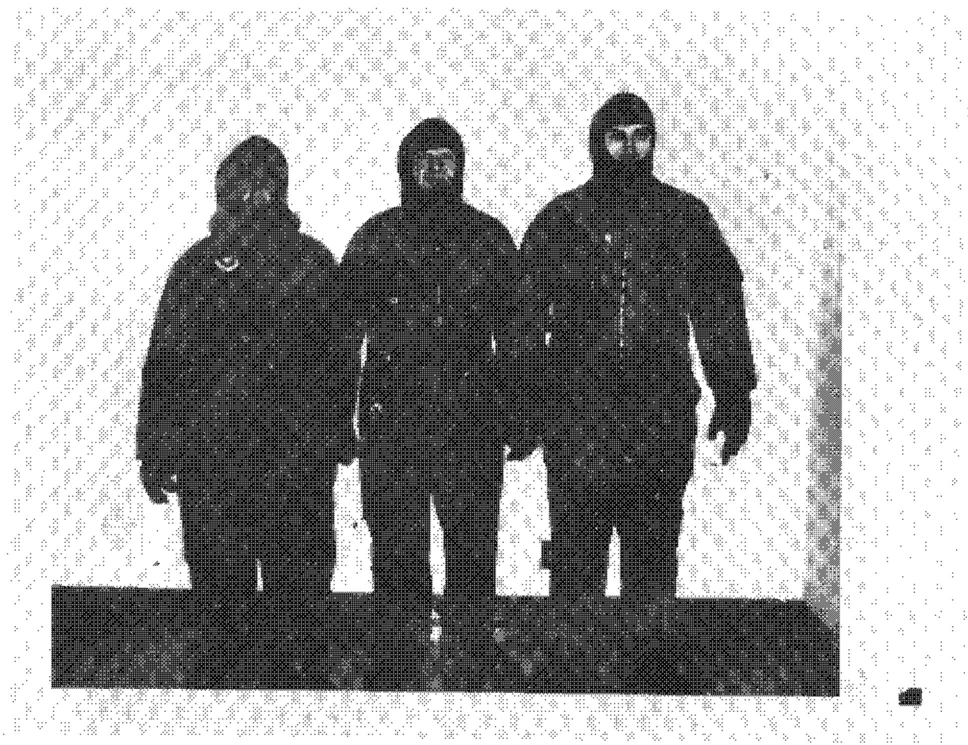

FIGURE 2. Subjects in wet suits and Air Force cotton flight suits.

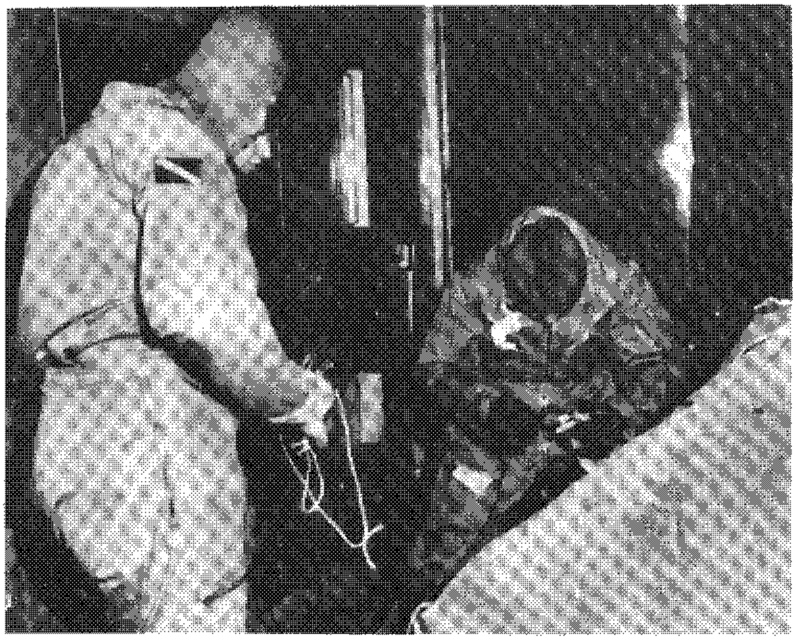

FIGURE 3. Subjects during delay encountered due to entangled leads.

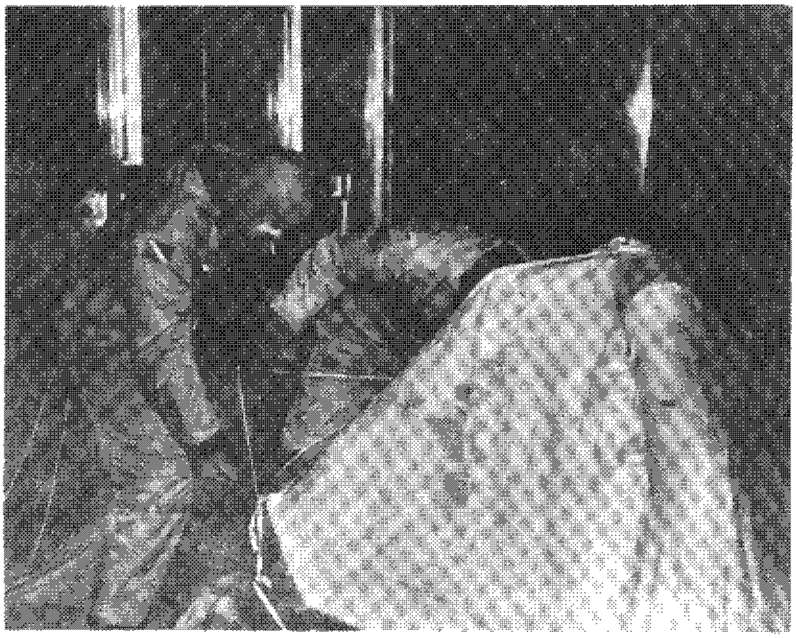

FIGURE 4. Subjects entering Beaufort raft.

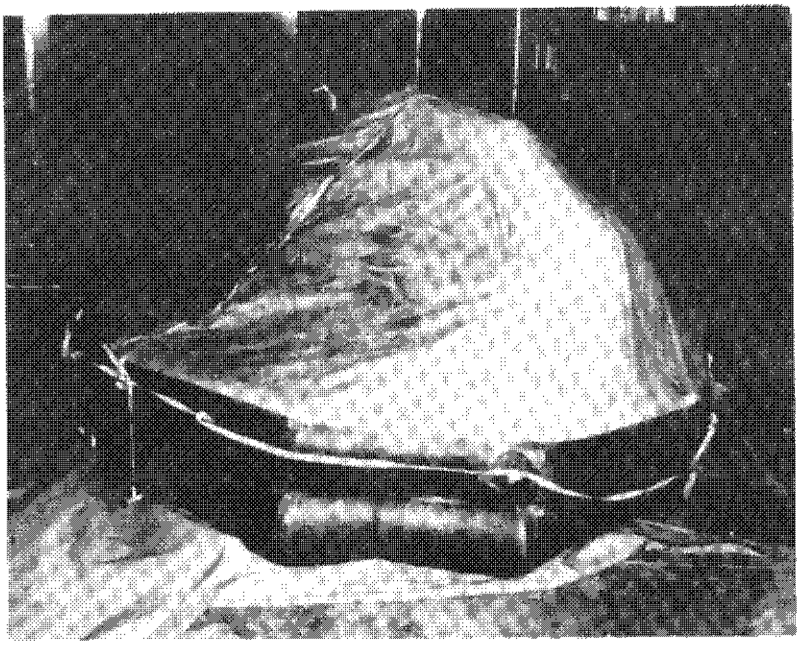

FIGURE 5. Subjects inside Beaufort raft and with canopy secured. Note shoulders of one subject against canopy. Camera was facing 45° into the wind. Ground cloth was used for protection of raft against rough floor.

EVALUATION OF SAFETY AND SURVIVAL EQUIPMENT REMOVED FROM AIRCRAFT SUBMERGED AT LOCK HAVEN, PENNSYLVANIA, DURING HURRICANE AGNES

Ernest B. McFadden

I. Background.

The equipment described in this report and evaluated in the survival tank of the Civil Aeromedical Institute was aboard an aircraft that sustained water damage at Lock Haven, Pennsylvania, during Hurricane Agnes in June 1972. An evaluation was conducted to assess the capability of this equipment to withstand adverse environmental rigors and not lose functional capability.

II. Description of Equipment.

All equipment was carefully removed from the shipping container and photographed. Inspection indicated that most items were contaminated with mud and other evidence of fresh-water immersion. Items received were as follows:

Life preserver waistcoat:
- Reference no. 22C/NIV (MK 14 with Velcro closure)
- Serial no. 089
- Order no. KX/R/922/CB22(a)
- Manufactured October 1970 by Beaufort (Air Sea Equipment, Ltd.), Beaufort Road, Birkenhead, Great Britain
- (Life preserver was heavily soiled with mud, indicative of fresh-water immersion.)

Right pocket (of life preserver):
1. Miniflares kit: eight flares and pencil launcher
2. Saltwater activated battery 5J/3411--MCM 1969 (double element)

Left pocket (of life preserver):
1. Emergency code sheets, plastic
2. Signal mirror and plastic sight
3. Sealed package of sea marker dye
4. Unidentified sealed package of caked powder encased in blue plastic with yellow opening strip--possibly shark repellent
5. Emergency radio--Burnadept Electronics, Ltd., serial no. 103, BE-375, SARBE-5. Set to transmit on emergency channel of 243 MHz with auxiliary channel (speech only) on 282.8 MHz; battery part no. 69053, serial no. 104, manufactured February 11, 1972.

Raft--single-seat liferaft, type C-2:
- Drawing ALD 2000
- Serial no. 04T
- Order no. K22C/345
- Date of manufacture--July 1970
- Contents:
  1. Three oral inflation tubes
  2. One repair plug
  3. One bailing bucket (collapsible) and one sponge
  4. Raft case and sea anchor

(The single-seat liferaft is inflated by a carbon dioxide compressed gas cylinder; the main tube is equipped with a pressure relief valve to preclude overinflation. The main tube is also equipped with an oral inflation tube. For thermal insulation, the inflatable raft floor and poncho-type raft canopy are equipped with oral inflation tubes and are dependent on this mode of inflation.)

Blue bag:
1. One 6½-oz tin of emergency flying ration MK IV, reference no. 27P/25, packaged 9/68.
2. Oxygen masks, continuous flow, rebreather bag and sponge dilution ports, nasal mask only.
3. Oxygen mask, continuous flow, rebreather, open-port dilution with an MC 254AP/0 ANB MCL microphone in mask. Extension cord to mask equipped with a round press-to-talk switch assembled by the Zep Aero Co.

Loose items in shipping box:
1. Permutit seawater desalting apparatus, bag leaking desalting chemical powder.
2. First aid kit, ejection seat and survival, 6545-99-211-0734, pack no. 2:
   - Antiseptic cream
   - Sunscreen and insect repellent cream
   - Adhesive dressings
   - Standard dressings
   - Water bag

   Expiration date: March 1972

III. Survival Tank Evaluation.

Prior to survival tank testing and evaluation, all accessories were removed from the pockets of the life preserver waistcoat to prevent immersion of the accessories or contamination of the survival tank water by sea dye, desalting chemical, and/or what appeared to be shark repellent. The emergency radio was detached from the antenna and coaxial cable leading to the antenna. The antenna and coaxial cable were not removed from the jacket since this would have required unpacking the vest buoyant compartments, which were enclosed in an outer envelope secured by Velcro tape.

The life preserver waistcoat was donned by a 212-pound male subject and appropriate sizing adjustments were completed. The liferaft was packed in a soft case with Velcro closures and equipped with a retention strap terminating in a male quick-disconnect fitting. The male quick-disconnect fitting was inserted into the corresponding fitting of the life preserver waistcoat to secure the liferaft to the life preserver waistcoat by a 6½-foot tether or retention line. The subject entered the water carrying the liferaft in his right hand by the strap handles of the raft package. Once in the water, he grasped the beaded life preserver waistcoat inflation handle in his left hand and jerked the handle to initiate activation of the life preserver waistcoat, which rapidly and fully inflated. He then retrieved the liferaft by means of the tether and pulled the inflation handle of the liferaft, which fully inflated. The raft was easily righted and, with surprisingly little effort, the subject boarded the liferaft and secured the protective poncho-type canopy.

All survival tank evaluations were carried out in calm water at a temperature of 82° F.

A. Liferaft Performance. The sea anchor of the liferaft deployed as designed and the stabilizers on the underside of the raft appeared to provide good raft stabilization. The poncho-type raft canopy was easily sealed by use of the combination of Velcro and snap fasteners. The emergency radio antenna became detached from the life preserver waistcoat during the survival tank evaluation and sank to the bottom of the tank. Had it been connected to the emergency radio, it might still have become disconnected from the life preserver mounting socket, but it would have been effectively fastened to the life preserver by the coaxial cable connected to the radio.

B. Life Preserver. The life preserver waistcoat provided excellent buoyancy and was so designed as to provide increased buoyancy in an advantageous area; i.e., ventrally with a significant portion below the level of the lungs. Body attitude was maintained at a desirable 25° to 30° back from the vertical. Head and neck support to maintain the respiratory openings above water level (in case of loss of consciousness of a survivor) was adequately maintained by the design of the inflatable chambers.

C. Survival Radio. The emergency radio (BE-375, SARBE-5) was equipped with a special switch to test operational condition of the radio without activation of the emergency transmitter. A green light indicated a GO status and a red light indicated a NO-GO condition. On activation of the test switch, neither light operated. The special battery was removed and checked with a vacuum tube voltmeter and was found to be totally discharged.

Since replacement batteries were not available and there was no indication of the type and voltage of the battery, further evaluation of the emergency radio was not possible at this time.

D. Seawater Desalting Apparatus. It appeared that some of the chemical blocks in the desalting kit had crumbled, possibly because of penetration of moisture into the bag in which they were sealed. On handling, small amounts of the powdered chemical leaked from the bag. It is probable that, although its performance had been degraded, the desalting apparatus would still have been capable of desalting limited quantities of water.

E. Sea Marker Dye. The sea marker dye was contained in a watertight flexible plastic container and appeared to be completely sealed and functional.

F. Shark Repellent. Although no visible markings were noted, the watertight flexible package containing what is thought to be shark repellent appeared to be intact and functional.

G. First Aid Kit. The small first aid kit was heat sealed in a heavy flexible plastic container and exhibited no signs of leakage of moisture into the container. The expiration date, however, was listed as March 1972.

H. Oxygen Masks. A small blue cloth bag, not designed for survival equipment packaging, contained two oxygen masks. These items are not normally (and possibly were not in this case) packaged with survival equipment. The bag also contained a small (6½-oz) canned emergency ration, an item that would frequently be found in the survival kit. The open-port rebreathing mask was in poor condition, and the rebreathing bag indicated signs of deterioration. This mask was equipped with a microphone and push-to-talk switch. On connection in a communications system, the microphone and switch were functional.

I. Water-Activated Battery. The protective plugs of the water-activated battery were in place and it appeared that water had not entered and activated the battery and survivor locator light attached to the life preserver waistcoat.

J. Emergency Signaling Kit (Miniflare). All eight flares were fired vertically and attained a height of 300 to 400 feet. Burnout occurred before return to the ground. Specifications of signal flares frequently require burnout before return to the ground, as early design flares have been indicted for initiating forest fires in wilderness areas. There were no failures or duds in the eight flares provided in the flare kit.

HIGH-DENSITY LOADING OF MULTIPLE-OCCUPANT FLOTATION DEVICES

Ernest B. McFadden
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Clyde C. Snow

I. Introduction.

Ditching at sea by commercial transport aircraft involves the deployment of large, interiorly stowed liferafts to protect the survivors from immersion, exposure, and drowning. Most current jet aircraft are equipped with inflatable escape slides that are deployed externally at the exits. Such slides exhibit fundamental characteristics that are required of a flotation device for large numbers of survivors in the event of a sea ditching. Modifications of these slides have given rise to the slide/raft with a design goal of improving seaworthiness and capacity without compromising land evacuations. In a special study (1) of the ditching of a DC-9 on May 2, 1970, near St. Croix, V.I., the National Transportation Safety Board (NTSB) has recommended that the Federal Aviation Administration (FAA) expedite the development of the slide/raft combination and require installation of this device on all U.S. air carrier aircraft engaged in extended overwater flight.

II. Method.

A. Anthropometry. The Society of Automotive Engineers (SAE) S-9 Cabin Safety Committee sponsored a series of tests of prototype slide/rafts furnished by various manufacturers at Fort Worth, Texas, during December 1970. These tests were designed to measure freeboard, buoyancy, and occupancy characteristics of various slide/rafts. The FAA Civil Aeromedical Institute (CAMI) was requested to assist in these evaluations by providing anthropometric measurement and description of the test subjects. Fourteen anthropometric measurements on each of 184 subjects were made by using the techniques described by Snow and Snyder (2). Several of the measurements were modified and a special apparatus was constructed to define the seating area and functional space requirements for subjects seated in positions similar to those they would normally assume in a liferaft. These special measurements in combination with the previously described measures were used to determine the individual seating area in square feet, as shown in Figure 1, when the legs were extended (A) and maximally flexed (B). Hip breadth (C) was measured with the legs extended and flexed as shown in A and B.

These data were subjected to computer analysis and the following regression equations developed.

Legs Extended

Area I = -1.9065 + 0.005043 (weight, lb) + 0.027620 (height, cm) -0.018387 (sitting height, cm) +0.011676 (hip breadth, cm)

Legs Flexed

Area II = 0.162961 +0.006283 (weight, lb) + 0.011807 (height, cm) -0.023520 (sitting height, cm) +0.026405 (hip breadth, cm)

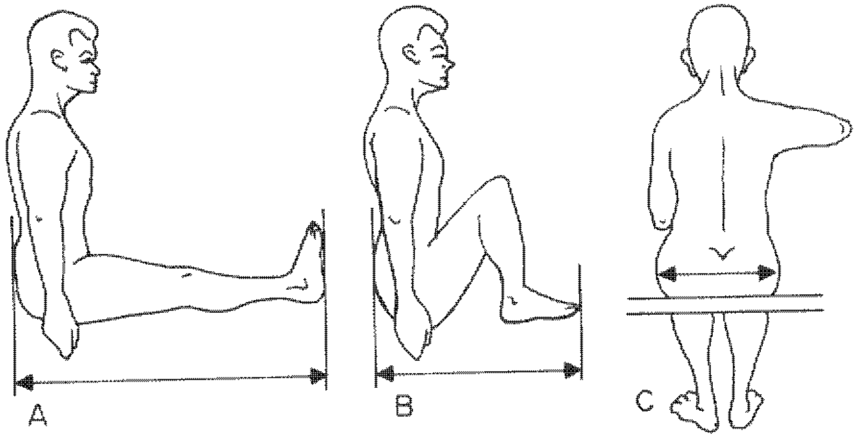

FIGURE 1. Measurements of hip breadth (C) were taken with subjects positioned as shown in (A) and (B).

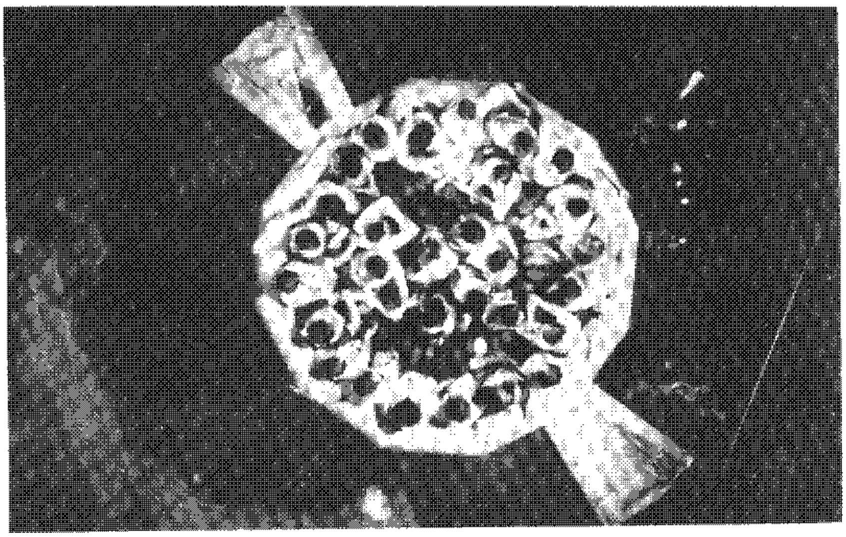

FIGURE 2. High-density loading for 8-hr endurance test.

Using the above regression equations we determined that a few simple measures by individuals without special training could be used to predict the subject seating areas. The confidence of this method as opposed to the more elaborate measurements is presented in Table 1.

TABLE 1. A Comparison of Measured Subject Areas vs. Calculated Areas Derived From the Four-Factor Regression Equation

Test	Legs Extended (Area) Total (ft^2) Measured	Legs Extended (Area) Total (ft^2) Calculated	Legs Extended (Area) Difference (percent)	Legs Flexed (Area) Total (ft^2) Measured	Legs Flexed (Area) Total (ft^2) Calculated	Legs Flexed (Area) Difference (percent)
Group I (42 subjects)	137.2	139.2	1.4	89.5	90.5	1.1
Group II (37 subjects)	122.1	124.1	1.7	78.1	79.3	1.5
Group III (10 subjects)	32.5	33.2	2.0	21.4	21.2	-0.9

Note: Number of subjects actually used, reflected in Table 2, was adjusted to the design of the loading density under study.

TABLE 2. Subject Profile: High- vs. Low-Density Loading Tests

Test	Subject Weight (lb) Total	Subject Weight (lb) $\bar{x}$	Measured Subject Area (ft^2) Legs Extended Total	Legs Extended $\bar{x}$	Legs Flexed Total	Legs Flexed $\bar{x}$
High Density N=29	4,908	169.2	96.5	3.33	61.6	2.13
Low Density N=10	1,677	164.3	32.5	3.25	21.4	2.14

B. Extended Duration Testing. Large-capacity ratings are desired by the air carriers because of door design, stowage limitations, and available exits capable of accommodating slide/rafts.

Subsequent testing at CAMI was carried out to evaluate the effects of extended duration occupancy of liferafts under high-density loading. Because of the numerous slide/raft prototypes evaluated in the Fort Worth tests, subjects occupied the slide/rafts under high-density loading for only a few minutes at a time.

A preliminary test using CAMI personnel was conducted to assist in the development of an experimental design. For a subsequent 8-hour endurance test to evaluate high-density loading, 47 male university students were used as subjects. Twenty-nine of these subjects were placed in a 20-man liferaft with a resultant loading density of 2.45 ft^2 per subject. Subject seating areas are shown in Table 2.

After loading (Figure 2) the subjects were not allowed to stand up, sit on the flotation ring, or change their relative positions. The test was conducted in an indoor survival tank and subjects were not preinformed as to the duration of the test. As an incentive to continuation, subjects were paid at an increasing rate with duration of participation.

Eight additional measured subjects were placed in a comfortable room isolated from the test area but confined to the seated position in comfortable chairs. These subjects were maintained as a reserve or replacement pool should any of the subjects elect to abandon the raft. In case of abandonment, the subject was replaced with another subject exhibiting similar anthropometric measurements who, in turn, occupied the identical space that the first subject had abandoned. Using this technique, we maintained the same loading density throughout the test. A control test was conducted the following day with only 10 subjects for the same duration and under the same conditions with the exception that the loading density was a generous 7 ft^2 per subject. Selected anthropometric measurements were taken and urine samples collected prior to and immediately following the 8-hour tests. These parameters were examined for responses within the particular exposure and for differences between the density loadings. While in the raft, the subjects were allowed free access to food (a carbohydrate candy) and water; the quantities consumed were recorded on an individual basis. Although provisions were available, all subjects refrained from voiding while in the raft. Test surveillance was maintained by the authors and a team of psychologists. In addition, time-lapse photography was recorded from directly overhead while continuous video and directional sound recordings were obtained horizontally from a 60° angle. The ability of each subject to swim following the 8-hour exposure was tested by having him vacate the raft and swim across the survival tank.

C. Open Water Testing. The testing of flotation devices such as rafts or slide/raft combinations in survival tanks or pools greatly restricts the severity of the test environment. Recognizing these limitations, open-water trials were conducted at Lake Eufaula, Oklahoma, to observe the seaworthiness and capacity ratings of a large flotation device under field conditions. For these trials, a PICO double-lane slide/raft 26 feet in length, designed for the DC-10, was used. Area calculations of a slide/raft are influenced by judgments that must be made with respect to usable and nonusable surfaces on both ends of the slide. With these considerations, a usable area of 193 ft^2 was calculated for this slide/raft. An inflation pressure of 2 psig was maintained during these trials. The supplementary inflation cuff located on the aircraft attachment end of the slide/raft was not inflated. Both flotation tubes were inflated during the first three trials while the bottom flotation tube was not inflated for the remaining four trials. The canopy was inflated and deployed during test 6 only.

The subject population was provided through the cooperation of local Naval Reserve units. Consequently, the subject population was considerably biased with a high percentage of males between 20 to 40 years of age and of medium stature and weight. Because of logistical problems, anthropometric measurements for each subject were taken on the day preceding the lake test. Seating areas with legs fully extended and fully flexed were derived through the regression equation previously presented and are shown in Table 3. In addition, seating areas were calculated with respect to the number of subjects vs. area of the raft and are as follows:

Test 1: 44 subjects in 193 ft^2, 4.4 ft^2/subject
Test 2: 53 subjects in 193 ft^2, 3.6 ft^2/subject
Test 3: 65 subjects in 193 ft^2, 3.0 ft^2/subject
Test 4: 44 subjects in 193 ft^2, 4.4 ft^2/subject
Test 5: 53 subjects in 193 ft^2, 3.6 ft^2/subject
Test 6: 44 subjects in 193 ft^2, 4.4 ft^2/subject
Test 7: 65 subjects in 193 ft^2, 3.0 ft^2/subject

Motion picture cameras were attached to a gyrostabilized mount positioned atop a 20-foot floating tower for recording purposes. Supplementary waves were generated through the use of large power boats.

III. Results.

A. Extended Duration Testing. The experimental design of this evaluation assumed the possibility that extreme crowding and the restriction of mobility could produce vascular pooling and limitation of blood flow in the lower extremities. Complaints by the subjects of numbness and comments that their feet and legs had "gone to sleep" indicate that this did occur to some extent. However, the swimming test required at the end of 8 hours' immobilization did not indicate a significant impairment in the subjects'

TABLE 3. Subject Profile: PICO Slide/Raft Test

Load	N	Subject Weight (lb) Total	Subject Weight (lb) $\bar{x} \pm SD$	Subject Area* (ft^2) Legs Extended Total	Legs Extended $\bar{x}$	Legs Flexed Total	Legs Flexed $\bar{x}$
1	44	7.459	169.5±28.1	146.4	3.33	99.6	2.26
2	53	8.906	168.0±27.3	175.1	3.30	119.0	2.24
3	65	11.071	170.3±29.8	216.4	3.33	147.8	2.27

*Area calculated from the four factor regression equation; weight, stature, sitting height, and hip breadth.

swimming ability. It was observed that all subjects appeared to be capable of acting in the interest of their own survival should the raft capsize. Tests of urine for albuminuria and measurements of ankle circumferences for signs of vascular pooling were either negative or inconclusive.

Table 4 presents an analysis of the pretesting and posttesting body weights as corrected for food and water consumption and for urine production.

The statistical significance of the difference in insensible body weight loss indicates the crowded condition to be the more stressful. Results of psychological surveillance and review of video recording, motion picture film, subject questionnaires, and mood analysis failed to reveal any outstanding behavioral changes.

Excess movement by any one of the subjects in the raft frequently initiated a chain reaction and displacement of the other occupants, who voiced complaints of discomfort and pain. As the test progressed it was noted that one particularly restless subject began to bear the brunt of hostile comments from other occupants.

During the high-density endurance test one subject withdrew from the raft after 5½ hours and another after 7 hours. In each of these cases, withdrawal was considered involuntary because of an emergency or employment commitments.

Immediately on withdrawal of each of the subjects, his exact position in the raft was filled with another subject of similar anthropometric characteristics from the reserve pool.

TABLE 4. Subject Response: High-Density vs. Low-Density Loading, 8-Hour Test

	High Density	Low Density
N	29	10
Subject weight		
Total	4,908 lb	1,677 lb
$\bar{x}$	76,838±9,946 g	76,142±7,734 g*
Change in weight		
$\bar{x}$±SD	761±247 g	578±150 g**
Percent	0.983±0.260	0.765±0.199
Food consumption		
$\bar{x}$±SD	293±137 g	221±82 g
Water consumption		
$\bar{x}$±SD	269±195 g	200±94 g
Urine production		
$\bar{x}$±SD	327±113 g	352±106 g
Correlation coefficient		
Subject weight to:		
Change in weight	0.592	0.170
Food, weight	-0.142	-0.210
Water, weight	-0.173	0.060
Water consumption to:		
Urine, weight	-0.169	-0.416

*No significant difference, t test.
**Significant at the 0.05 level, t test.

B. Open Water Testing. Results of the open water testing as related to stability, seaworthiness, and configurational changes are best obtained through review of cinematographic film of the test sequences.

Figure 3 demonstrates the buoyancy and density loading of the 26-ft PICO slide/raft occupied by 65 subjects to a density of 3.0 ft^2 per subject.

FIGURE 3. Maximum load configuration during open water testing of the PICO slide/raft.

The lower tube and inflation cuff at the girt end of the slide are not inflated. While buoyancy was adequate to support the subject load, survival under conditions of low water temperatures would be limited because of large quantities of water in the raft. With both flotation tubes inflated there was adequate buoyancy for all subject density loads evaluated. However, with the inflation cuff in the uninflated mode, the girt end configuration of the slide/raft was such that subjects in this area experienced difficulty in staying aboard.

The canopy, which is erected by manual operation of valves connected to the main flotation tubes, inflated and functioned satisfactorily in the 10-15 mi/h winds prevailing at that time. The configuration of the center or slide surface of the slide/raft is such that each subject, as each opposes another, is provided a back-to-foot length of approximately 25 to 27 inches in each lane. However, this area may be extended by subjects' interpositioning their legs.

Interspaces down the center of this compartment may be filled with additional occupants, but they will not have back support. The side or outrigger compartments are only 32 inches wide but staggering of subjects to make maximum use of back support is still possible.

IV. Discussion and Conclusion.

Test exposure of young healthy subjects indicated they were capable of tolerating high- and low-density occupancy of liferafts for 8 hours without any detected physiological or performance decrements. However, such findings can be considered only as optimum baselines for tolerance because they were conducted indoors without wave or weather effects and without the other stresses attendant in actual emergencies. The test subjects were also atypical of the airline passenger population in that no females or very young or elderly subjects were included. In addition, the presence of passengers with medical conditions or injuries sustained during an actual ditching would further complicate survival under conditions of high-density loading. Open water evaluation of the 26-ft PICO slide/raft indicated adequate buoyancy and stability under moderate wave conditions (Beaufort Scale 3-4) with the maximum loading evaluated (65 occupants, 3.0 ft^2 per occupant). For the maximum usage of space available in this slide/raft, an orderly arrangement of subject seating must be instituted. To prevent occupants near the girt end of the slide from being forced overboard, crewmembers or survivors must be made aware of the necessity for manually inflating the inflation cuff.

REFERENCES

1. National Transportation Safety Board: Special Study, Passenger Survival in Turbojet Ditchings (A Critical Case Review), Report No. NTSB-AAS-72-2, 1972.

2. Snow, C. C., and Snyder, R. G.: Anthropometry of Air Traffic Control Trainees, FAA Office of Aviation Medicine Report No. AM-65-26, 1965.

EVALUATION OF AIRCRAFT SEAT CUSHION FLOTATION CHARACTERISTICS

Ernest B. McFadden

I. Cushion Identification.

An aircraft seat cushion of German manufacture, described as being in widespread use by airlines operating in Europe, was forwarded to the Civil Aeromedical Institute (CAMI) for evaluation of its flotation characteristics.

The light-green cushion was not encased in a decorative cover, bore no identification markings, and appeared to be constructed of open-cell molded foam. Of a rather complex shape, the cushion measured 44 cm wide by 44 cm long, exclusive of a 27-cm-wide, 13-cm-high, and 6-cm-thick back panel. Thickness of the seat cushion ranged from 7 cm at the rear portion of the cushion to 14 cm at its forward curved edge. Documentation indicated that the seat cushion was constructed of an open-cell, cold-cured, flame-retarded, polyglycol-polyurethane foam.

Examination revealed that air would pass freely through the structure of the seat-cushion foam and the manufacturer apparently had not tried to design the cushion to comply with Federal Aviation Administration (FAA) Technical Standard Order TSO-C72b, Individual Flotation Devices, which requires that the device maintain no less than 14 lb (6.35 kg) of buoyancy for a period of 8 h.

II. Flotation Evaluation.

To determine the buoyancy of the cushion, we conducted an evaluation on August 17, 1977, in the CAMI survival tank using the following general procedures as specified in TSO-C72b, paragraph 7.0.1.b:

A. Time-lapse motion picture cameras were positioned to allow documentation of the cushion's performance.

B. The cushion was placed in the water and covered by a polyethylene netting exhibiting neutral buoyancy.

C. A specially prepared and calibrated brass weight having an underwater weight of 14 lb (6.35 kg) was connected to the polyethylene netting and suspended underwater from the netting containing the cushion, thereby imparting a static load of 14 lb (6.35 kg) to the seat cushion.

D. The static test was continued for a period of 10 min, after which time the cushion was observed to have lost considerable buoyancy. However, sufficient air was still entrapped in the open-cell structure to support the 14-lb (6.35-kg) load. Stabilized in this condition, without movement and undisturbed, the cushion might have continued to support the weight for an indefinite period of time.

E. Following completion of the 10-min static test, we removed the weight and netting. The cushion was then used to support a human subject as described in TSO-C72b, paragraph 7.0.1.b, for a period of 5 min. In this mode the subject's arms encircled the cushion, which was held at chest level. No special squeezing or compression of the cushion was tried, although during movement and positioning of the cushion to the chest, air bubbles were emitted from the cushion's foam structure.

F. After the cushion had supported a human subject for 5 min, the polyethylene netting was placed over the cushion and the 14-lb (6.35-kg) brass weight was reconnected. On connection of the weight, the cushion immediately sank to the bottom of the survival tank. Sinking occurred 19 min 23 s after the cushion was placed in the water. Although the static and human subject tests were 10 and 5 min respectively, about 4½ min were required to remove and reapply the weights and retention netting, after which time the cushion remained unloaded.

Top, side, and bottom views of the cushion are shown in Figures 1, 2, and 3, respectively.

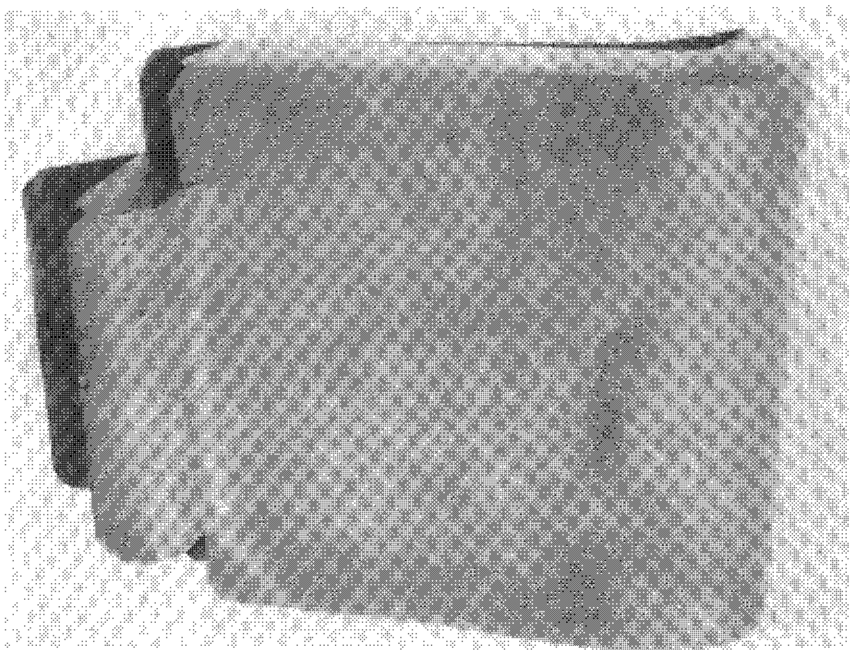

Figure 1. Top view of aircraft seat cushion.

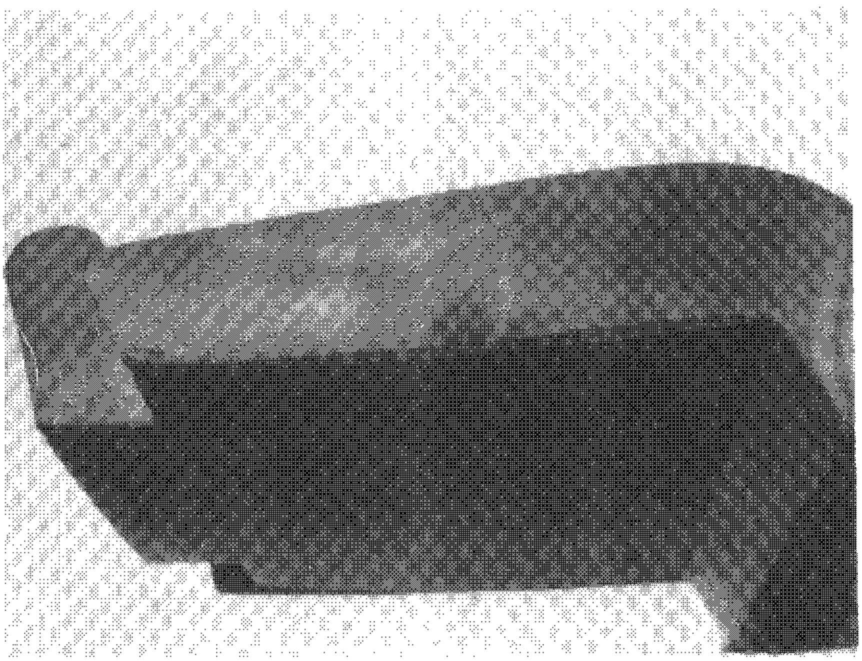

Figure 2. Side view of aircraft seat cushion.

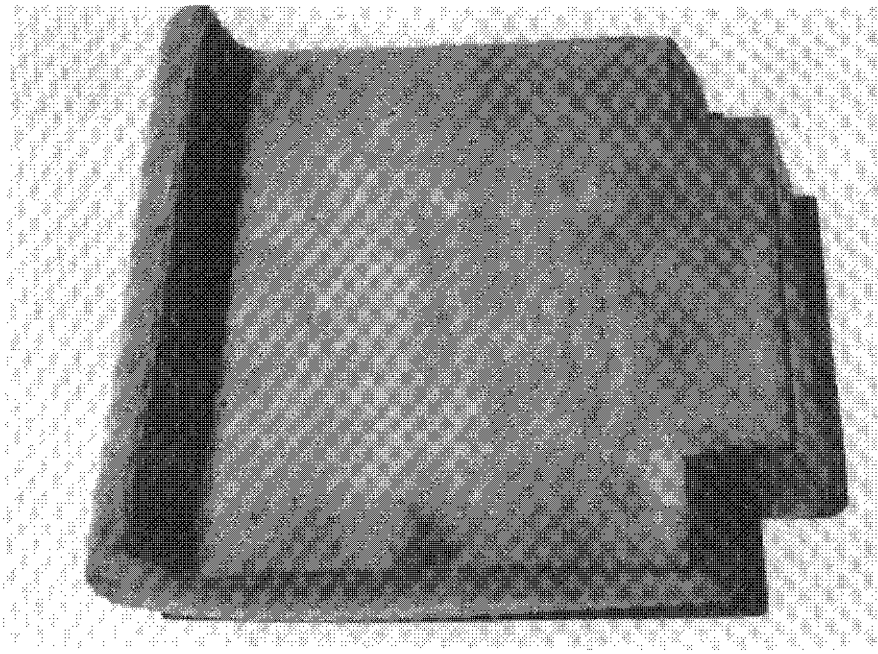

Figure 3. Bottom view of aircraft seat cushion.