

FLOTATION CHARACTERISTICS OF AIRCRAFT- PASSENGER SEAT CUSHIONS

Ernest B. McFadden, M.S.
James M. Simpson

Approved by



J. ROBERT DILLE, M.D.
CHIEF, CIVIL AEROMEDICAL
INSTITUTE

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FEDERAL AIR SURGEON

April 1966

FEDERAL AVIATION AGENCY
Office of Aviation Medicine

ACKNOWLEDGMENTS

The authors gratefully acknowledge the contributions of Dr. Vincent Fiorica and Don Desteiguer, who interrupted a busy schedule to conduct the body-density determinations. Acknowledgment is also made to F. F. Winters, cinematographer, who under difficult circumstances filmed the tank and field evaluations from both the surface and underwater for later study and analysis.

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I. Introduction.

Due to community pressure and noise-abatement programs, takeoff and landing flight patterns of turbine-powered aircraft have been increasingly restricted to the airspace over relatively uninhabited areas of water. Because of these trends, if and when an aircraft accident occurs, the probability of it involving water has been proportionally increased. In the event of a survivable accident in water, provisions for flotation of passengers and crew until rescue can be effected become a significant problem.

The domestic air carrier is not required to carry life preservers or rafts on aircraft operating no further than 50 miles from land. Nor is it realistic to require the domestic air carrier to comply with the same requirements as the overseas operator, whose life preservers and rafts are designed for longer-term, open-sea survival.

In a recent report by Townshend¹ covering 10-year history of 102 ditchings of transport-category aircraft, it may be noted that 30 of 36 premeditated ditchings where life rafts were not provided, 30 occurred within 5 miles of shore. Time required to effect rescue, available in only a few instances, varied from 30 minutes to 6 hours.

At the request of the Flight Standards Service of FAA, a study was initiated to determine the flotation characteristics of items currently aboard domestic aircraft in sufficient quantity to provide individual passenger and crew flotation.

Numerous items were surveyed, and, of these items, the most likely utilizable consisted of pillows and seat cushions. Pillows were found to be inadequate in size and volume to provide adequate flotation, unequally distributed about the cabin, frequently insufficient in number, and difficult to render waterproof and at the same time maintain the pillow's comfort characteristics.

It should be noted here that the flotation capability of escape slides as group flotation devices was not disregarded. A properly deployed escape chute when equipped with sufficient survivor hand holds has considerable potential as a group flotation device. As an individual flotation device, however, the aircraft seat cushion fulfilled the following criteria:

1. Potential size and volume to provide adequate flotation.
2. Light weight.
3. Available in an equivalent or greater number than passengers aboard.
4. Distributed equally with respect to passenger distribution throughout the cabin.
5. Instantly available.

On July 15, 1963, the Federal Aviation Agency issued Technical Standard Order (TSO) C-72² covering individual flotation devices for aircraft flying no further than 50 miles from land. One of the provisions of this TSO stated that an individual flotation device must provide a minimum of 14 pounds of bouyancy for 8 hours.

II. Methods.

Initial static tests of aircraft seat cushions consisted of placing the cushion in the survival tank. Sheet lead of approximately the same flat dimensions as the cushions was placed upon the upper surface of the cushion. The weight of the sheet lead and a small electrical recording device attached to the lead was accurately adjusted to a weight of 14 pounds. The test sample cushion was surrounded by an aluminum cylinder approximately 4 feet in diameter and 3 feet in height. This served as a wave shield and prevented disturbances of the water surface (generated elsewhere in the survival tank) being transmitted to the test cushion.

An event recorder was connected to the electrical indicating device. Time-lapse motion-picture cameras covered the flotation history of the cushions. A study of these films indicated that

this method was not entirely satisfactory. It appeared that loss of buoyancy was not equally distributed throughout the cushion, resulting in a shift in the center of gravity of the cushion. Thus, at the point where the cushion was nearly totally immersed (and sinking imminent), the cushion and its loading were quite unstable, having a tendency to roll over in the water. The method of loading the seat cushion accordingly was modified in order to obtain a more satisfactory procedure.

This new method consisted of placing a piece of semirigid metal hardware cloth of the same dimensions as the cushion on its upper surface. A brass bar was suspended by small nylon lines from the four corners of the hardware cloth, thus lowering the center of gravity below the cushion. The displacement of water due to the volume of the submerged brass rod was determined and the total weight of all items exclusive of the cushion was adjusted to 14 pounds. Static tests utilizing this technique are summarized in Figure A1. (All Figures, A1 to A14, are in Appendix A.)

The technique for dynamic testing of seat cushions consisted of replacing the brass weight with a calibrated spring scale, arranged in series with the cushion and a rigidly attached bottom slip guide. Tension was then gradually applied to a line running to the surface. A reading of the initial force of buoyancy was obtained by a diver positioned near the spring scale. This required only a few minutes on each cushion. The cushions were then placed on the surface of the water along with a subject clothed in a lightweight summer flight suit and tennis shoes. Female subjects were clothed in a swim suit under a dress or pair of slacks. The subjects were instructed not to squeeze the cushion unnecessarily but just to hang on to the cushion, utilizing it for flotation as long as they could. In field tests, a safety buoy was provided nearby for the subject to utilize when the cushion failed to maintain adequate support. As soon as a subject deserted a cushion, it was picked up and retested for buoyancy as previously described. Field tests were performed in open water at Lake Tenkiller in Eastern Oklahoma. This exceedingly clear, fresh-water lake is approximately 35 miles long and from 2 to 4 miles wide. The water in the vicinity of the test area is approximately 70 to 100 feet deep. All tests were filmed by motion-picture and still photography for documentation and further study (Figure A2). The DC-7 cushions in Figure A2 were constructed of foam

rubber and were not designed to provide flotation but were evaluated for comparative purposes.

Another series of dynamic tests was performed in the CARI survival tank utilizing developmental seat cushions. Initial and final measurements were obtained using the previously described technique. In addition, in order to follow more closely the time course of buoyancy loss and check the accuracy of the spring-scale technique, subjects were periodically removed briefly from the cushions and tests utilizing combinations of lead weights were also conducted (Figures A3 and A4).

In order to continue the evaluations during the winter months and to simulate water-surface conditions, a wave generator was designed and constructed for use in the survival tank. This apparatus produces waves $1\frac{1}{2}$ to $2\frac{1}{2}$ feet in height. Because of the limited size and geometry of the survival tank, the resultant water-surface condition might be described as similar to a choppy or confused sea due to wave reflection from the tank walls and the resultant reinforcement. When compared to large swells such as occur in the Pacific, the simulated conditions appear to create greater localized turbulence. Subjects participating in those tests in which the cushion did not fail in a short period of time were relieved hourly with a total of eight subjects participating during an 8-hour evaluation.

In cooperation with CARI, a study was initiated by the Flight Standards Engineering and Manufacturing Field Extension to determine the reliability of a cushion-evaluation technique utilizing a machine to produce a dynamic load similar to that of a human subject. This apparatus was designed to repeatedly submerge the cushion to a predetermined depth, thereby increasing and relaxing the external pressure on the cushion. The machine was programmed to submerge the sample cushion to 10 feet at a rate of about 60 cycles/hour. In practice, however, the frequency averaged approximately 50 cycles/hour for a total of 480 cycles (9+ hours). Subsequent tests were conducted to a depth of $10\frac{1}{2}$ to 11 feet at 50 cycles/min for a total of 300 cycles (8+ hours). Equipment breakdown and interruptions in order to measure buoyancy account for the disparity between the number of cycles and total elapsed time.

Human and machine evaluations were performed on a variety of prototype seat cushions submitted by the manufacturers for evaluation

with respect to compliance with the intent of TSO C-72. Initially, only intermittent wave action could be simulated. The wave generator was constructed, and wave action could be simulated more consistently throughout the 8-hour evaluations.

In order to obtain some index for the magnitude of the load applied to the cushions, body-density measurements were made on 13 of the participating subjects (Table B1, Appendix B). The clothing the subjects wore during the cushion evaluations is included in the body-density re-terminations. These determinations were made in the Physiology Laboratory of CARI in a small tank specifically designed for determination of body composition. The procedure is similar to that of Goldman and Buskirk.³ A brief description of a determination may be found in Appendix B.

III. Results.

In the initial phases of this project, various types of open-cell polyether-foam seat cushions were pool-tested under a static load of 14 pounds and documented by time-lapse photography. Under these conditions, cushions successfully supported the static load for from 18 to in excess of 60 hours, therefore meeting the requirements of the TSO as written (Figure A1). These same types of seat cushions, when field-tested by human subjects in light wave action, provided less than 8 minutes of adequate flotation. Buoyancy in these dynamic tests utilizing human subjects decreased from in excess of 32.5 to 6.0 pounds in a 10-minute period (Figure A2). It is evident that although these types of cushions comply with the requirements of TSO C-72, they do not meet the intent of providing an adequate survivor-flotation device. In addition, these results emphasize the importance of a coordinated effort of both the product engineer and human-factors investigator in assuring an adequate and useful design.

Since the issuance of TSO C-72, seat manufacturers, fabricators, the airframe industry, and airlines have developed prototype seat cushions designed to provide individual survivor flotation. These cushion designs generally incorporate one or more of the following characteristics in order to provide adequate buoyancy:

1. Multifoam construction utilizing open-cell foam material for comfort and laminates or wedges of a closed-cell foam material essentially impermeable to water with indefinite flotation-duration characteristics.

2. Open-cell foam-construction cushions encased in a fine-weave cloth cover with stitched and sealed seams, which, although allowing air to pass freely during compression, are relatively impermeable to the passage of air and water following immersion.
3. A foamed-in-place cushion in which the basic open-cell polyurethane or similar material is mixed and allowed to react and expand in a mold. This produces a skin that is somewhat resistant to water penetration and in prototypes has been utilized singularly or in conjunction with a cloth cover to produce adequate buoyancy.
4. Open-cell cushions that have been dipped in a neoprene or similar latex compound, producing a watertight and airtight skin. The cushion is fitted with a valve that is left open during normal usage but must be closed prior to use as a flotation device.

Early prototype seat cushions failed during dynamic testing to provide human subjects with the 14 pounds of buoyancy specified in TSO C-72 (Figures A3 and A4). A prototype seat cushion designed to meet TSO C-72 requirements failed to provide adequate human flotation (Figure A5). This cushion was pre-exposed to -40°F for 8 hours. There was no indication that this affected the flotation characteristics of the cushion. A CV-990 cushion that was tested but not designed to provide survivor flotation failed in less than 8 minutes (Figure A6).

A new multifoam experimental prototype seat cushion of wedge-type construction was evaluated at Lake Tenkiller under field conditions for 8 hours. This same prototype cushion was subsequently subjected to a machine test (Figure A7).

A Boeing 727 prototype cushion consisting of the standard 727 polyurethane core sealed in a high-count linen cover provided very good flotation for a period of 8 hours (Figure A8). A rip or tear in this type of cover could produce a significant loss of entrapped air and buoyancy, depending upon the size and location of the rip and the position in which it was subsequently maintained by the survivor in the water.

A molded-foam crew seat (Massey Co.) enclosed in a hydrojac cover with a velcro closure and unsealed stitched seams was evaluated and provided the required buoyancy (Figure A9). The velcro closure separated during immersion minus the resultant residual buoyancy appears

therefore to be a function primarily dependent upon the permeability of the cushion's surface skin as a result of the molding process. It was subsequently determined by machine testing that the molded cushion without a cover would maintain the required buoyancy for 8 hours.

A B. F. Goodrich multifoam crew seat cushion similar in design concept to the 727 cushions in Figures A7 and A10 provided in excess of 14 pounds of buoyancy for 8 hours (Figure A12). The evaluations and the conditions under which each of the preceding cushions was conducted are summarized in Table 1.

IV. Discussion.

The typical aircraft-seat foam-cushion volume and displacement of water is such that, if the cushion remained totally impermeable to water, a buoyancy of from 30 to 50 pounds would be obtained, depending upon the size and volume of the cushion; i.e., tourist, first-class, or crew configuration. Most frequently, aircraft-seat foam cushions are compounded of a polyurethane or similar open-cell structural foam. The cellular structures are interconnected and vented to the exterior of the foam, allowing expulsion of air

TABLE 1. Summary of aircraft-seat-cushion flotation evaluations.

Figure	Test	Date	Cushion description	Test location	Water condition	Water temp (°F)	Remarks
1	Static, 14-lb static load	1-63	Aerothorn 48795 jet tourist Aerothorn 45248 jet tourist Aerothorn 43693 jet tourist	Survival tank	Still	78	17 hr 29.5 min—sank 19 hr 51 min—sank 96 hr 40 min—test terminated
2	Dynamic, human subjects	6-63	Aerothorn 727 jet tourist Aerothorn (two-foam) 43693 jet tourist Aerothorn (single-foam) 45248 jet tourist DC-7 (foam rubber)	Lake Tenkiller	Choppy waves 1 to 1½ feet	59	Buoyancy measured by tension technique
3	Dynamic, human subjects	1-64	Boeing 727 9718-7 (new) Boeing 727 11-MOC (used)	Survival tank	Still	84	Initial and final measurements by tension technique Intermediate measurements by use of lead weights
4	Dynamic, human subjects	1-64	AA 46-B 5500-1-H8/61 (new) AA 7786-1-D-5160 (used)	Survival tank	Still	85	Initial and final measurements by tension technique Intermediate measurements by use of lead weights
5	Dynamic, human subjects	4-64	727 new prototype 52722 mfg. to TSO C-72	Survival tank	Still	80	Buoyancy measured by tension technique. Cushion preconditioned by exposure to 40°F for 8 hr
6	Dynamic, human subjects	1-65	CV-990 single foam	Survival tank	Waves generated 1 to 1½ feet	87	Standard cushion not designated for flotation
7	Dynamic field, human subjects	7-64	B. F. Goodrich multifoam prototype	Field test—Lake Tenkiller; machine test—survival tank	1- to 1½-foot waves; Still	68	—
8	Dynamic, human subjects	2-65	Standard Boeing 727 Tourist Cushion (polyurethane core) encased in high-count linen (hydrojac) cloth cover. Sealed seams.	Survival tank	Waves generated 1½ to 2 feet	90	—
9	Dynamic, human subjects	1-65	Massey molded crew seat enclosed in high-count (hydrojac) cloth cover. Unsealed stitched seams. Velcro closure.	Survival tank	Waves generated 2 to 2½ feet	90	—
10	Dynamic (machine test followed by human subjects)	1-65	B. F. Goodrich experimental prototype multifoam tourist cushion. Designed to incorporate minimum closed foam.	Survival tank	Waves generated 2 to 2½ feet	87	Residual buoyancy partially dependent upon open-cell foam component. Cushion machine-tested 7 days prior to human testing. Open-cell portion of cushion may not have completely dried out following machine test.
11	Dynamic, human subjects	2-65	Boeing 727 tourist cushion encased in a high-count (hydrojac) cover with sealed seams. This assembly enclosed in an AA dress cover with two parallel red retention straps.	Survival tank	Waves generated 2 to 2½ feet	86	—
12	Dynamic, human subjects and machine test	2-65	B. F. Goodrich multifoam crew prototype cushion. Blue-canvas stitched unsealed cover.	Survival tank	Waves generated 2 to 2½ feet	87	Buoyancy increased following brief removal of cushion in order to add retention system. Apparently due to water draining from the open-cell foam component of the cushion.

during compression. The expulsion of air assures more comfortable seating characteristics than experienced with a closed-cell structure in which the air within the cell is compressed.

When utilized by a survivor in water, the loading applied by the survivor, his body movements, and the cyclic oscillations or bobbing in wave action are contributing factors that produce expulsion of air from the open-cell structure of the cushion. When immersed, the expelled air is subject to replacement by water, producing a loss in buoyancy in relation to the loss of air from the open-cell material.

In Figure A4, it may be noted that measurements taken by the tension technique indicate several pounds less buoyancy than the measurements utilizing a combination of lead weights. This difference appears to be a result of the surface tension. By monitoring the underwater spring scale, one may observe an instantaneous drop of several pounds in buoyant force of the cushion as it is pulled just below the water surface and the surface tension is broken.

Of course, if the cushion is pulled deeper, there is a gradual but significant drop in buoyancy with depth due to compression of air within the cellular structure of the foam.

Although several body- and cushion-flotation attitudes were tried, subjects tired rapidly since both hands were required to retain the cushion. Attempts to lie upon a buoyant cushion in the water with the hands free were only partially successful. Some subjects found the cushion to be relatively stable in light wave action when they assumed a spread-eagle supine position with the cushion centered under the maximum curvature of the lumbar region. When the arms and legs were pulled in toward the body, the attitude became less stable and the cushion slipped out from under the subject and was forcibly expelled away. This requires the survivor to swim a considerable distance unaided to recover the cushion. Under moderate wind conditions, the cushion may be blown away at such a rate that it may not be recovered.

One of the cushions was equipped with a single-strap, snap and adjustment fitting removed from a life preserver as shown in Figure A13.

In lieu of the above retention strap, a simple elastic band 2 to 3 inches wide permanently attached to both sides may be used. It is possible that this type of retention should be donned more rapidly than that shown in Figure A13.

Subjects wearing the cushion as shown in C and D of Figure A14 were maintained in a good flotation position. In addition, subjects wearing the cushion jumped into the water from 6- to 7-foot heights without difficulty or discomfort.

A retention strap of this type design frees the individual's hands for swimming, signalling, or assisting others. Overhand swimming is more readily accomplished with the seat cushion retained at the chest than with the airline-type life preserver, providing the cushion is not excessively wide.

A simple retention strap may be particularly valuable to prevent loss of the cushion when jumping into the water if the survivor is incapacitated or subjected to cold, wind, and wave action.

Retention straps as shown in A of Figure A14 result in the relaxed survivor being rotated backwards and finally stabilized with the head partially submerged and the cushion on top of his body. A three-component strap as shown in B of Figure A13 is better, but if utilized with the upper edge of the cushion at chin level does not maintain the survivor's mouth and nose sufficiently above the surface in turbulent water conditions. With the survivor's arms resting on the upper edge of the cushion as shown in C of Figure A13, the survivor's mouth and nose are elevated higher above the water, providing easier breathing with less effort in turbulent water. If the survivor extends his arms as shown in D, stabilization may be achieved with a minimum tendency for forward or backward rotation.

Various studies have been conducted on retention systems and life-preserver design in an attempt to develop a preserver that will adequately protect the unconscious or weak and incapacitated survivor. It is virtually impossible for a conscious subject to remain inert and flaccid, especially when his flotation attitude begins to deteriorate to the point where breathing is no longer possible. Macintosh and Pask have used a deeply anesthetized human subject⁴ and also a flotation dummy⁵ in order to study retention, buoyancy, and human-body attitudes as influenced by flotation-device design. In our studies, the conscious subject would attempt to remain relaxed and motionless. A slow rotation of the body would begin and the subject would attempt to persevere as

long as possible without resorting to corrective action (Figure A14).

When subjects were allowed to choose their positions, it was surprising that all male subjects chose to assume a seated position as shown by E in Figure A14. This choice was even more pronounced when the subjects were exposed to wave conditions, as this allowed them to float higher in the water and resulted in easier breathing and less exertion. Although this position appears to be quite unstable, it was a method of choice of a majority of the subjects after they had been in the water for a considerable time. The strap as shown in E, Figure A14, was successfully tested but is not recommended due to the final attitude a survivor would assume if balance were lost.

In general, the higher the head and chest can be buoyed above the surface of the water, the less the stress that will be imposed on the survivor by immersion; therefore, breathing can be accomplished easier and with more consistent regularity in turbulent water. In addition, the deleterious effects of profuse diuresis resulting from stimulation of the Gauer-Henry left-atrial volume-receptor reflex by the negative-pressure breathing required in partial water immersion may be reduced if a larger proportion of the chest can be maintained above the water surface. Diuresis begins in about 20 to 30 minutes after immersion when the antidiuretic hormone in the blood is depleted. Body-water loss under conditions of immersion to neck level may proceed at a rate of five to six times that of normal and approximate 2,000 to 3,000 cc.⁶

V. Conclusions.

1. Static buoyancy testing of aircraft seat cushions constructed of open-cell foam does not simulate actual conditions of use and provides deceptive and erroneous information.

2. A simple means of attaching the cushion

to the survivor's body should be incorporated in cushion or upholstery design.

3. The use of a combination of open- and closed-cell foam materials utilized in the proper geometry for aircraft-seat-cushion construction appears to provide a cushion that furnishes adequate flotation with respect to quantity and duration without significant sacrifice of seat-cushion comfort characteristics.

4. Open-cell cushions encased in a high-count tight-weave cloth cover with sealed seams have maintained in excess of 14 pounds of buoyancy for 8 hours and appear to be adequate if integrity of the cover is maintained.

5. The result of the previous tests reaffirm the requirement that personal, protective, and survival equipment destined for human utilization must be evaluated by dynamic human-factors testing in an environment simulating as near as practical the environment of anticipated usage.

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APPENDIX A

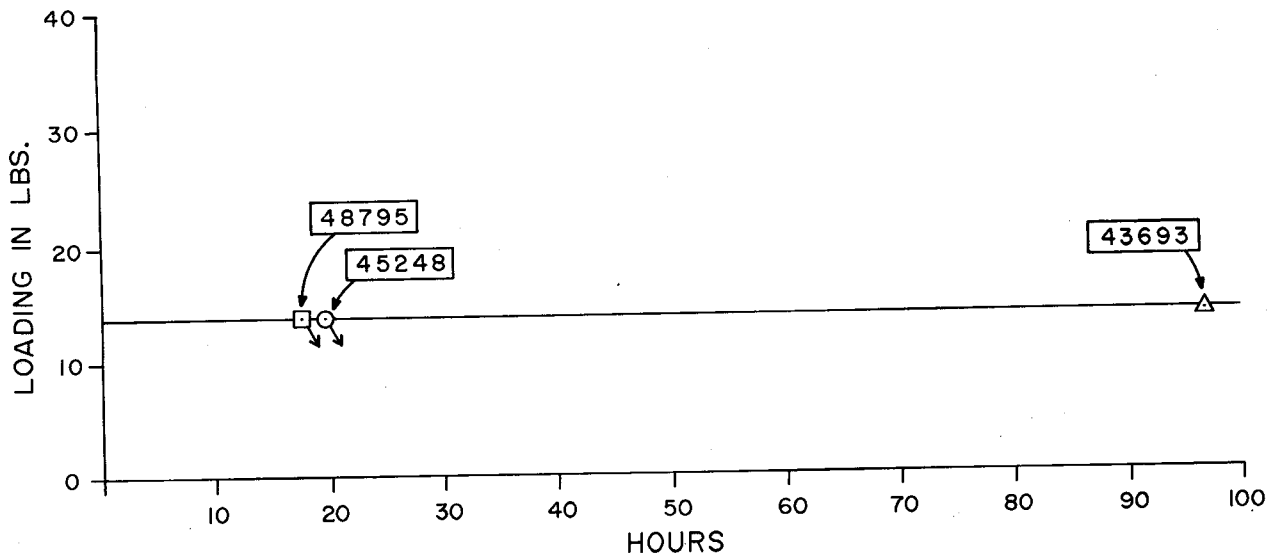


FIGURE A1. Static seat-cushion test conducted in March 1963. Cushions loaded with 14 pounds of weight and placed in still fresh water.

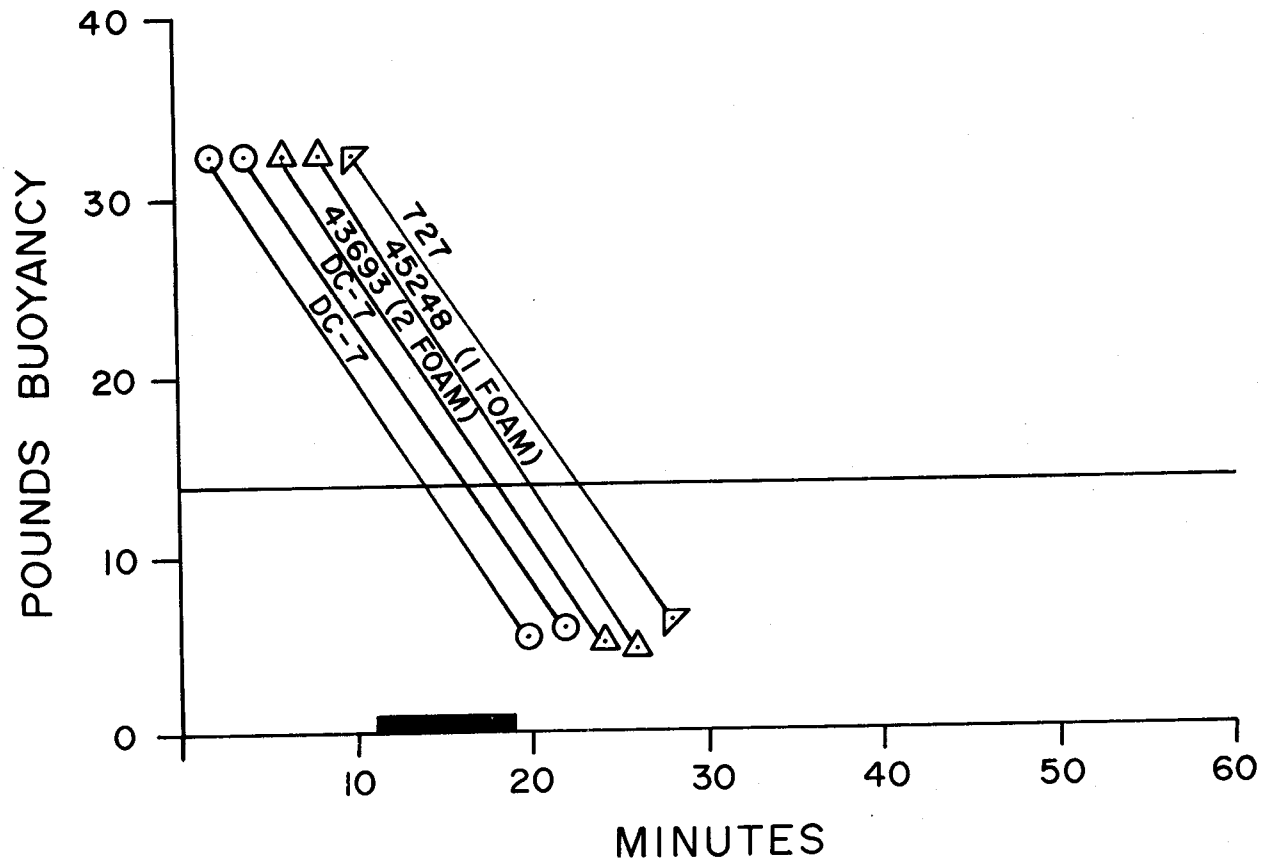


FIGURE A2. Dynamic seat-cushion test conducted in June 1963 at Lake Tenkiller in open fresh water and moderate wave action. Measurements of force of buoyancy by tension technique before and after 8 minutes of use by human subjects in open water. Black bar at base of graph indicates duration cushions utilized by subjects for flotation. Subjects clothed in flight suits and tennis shoes.

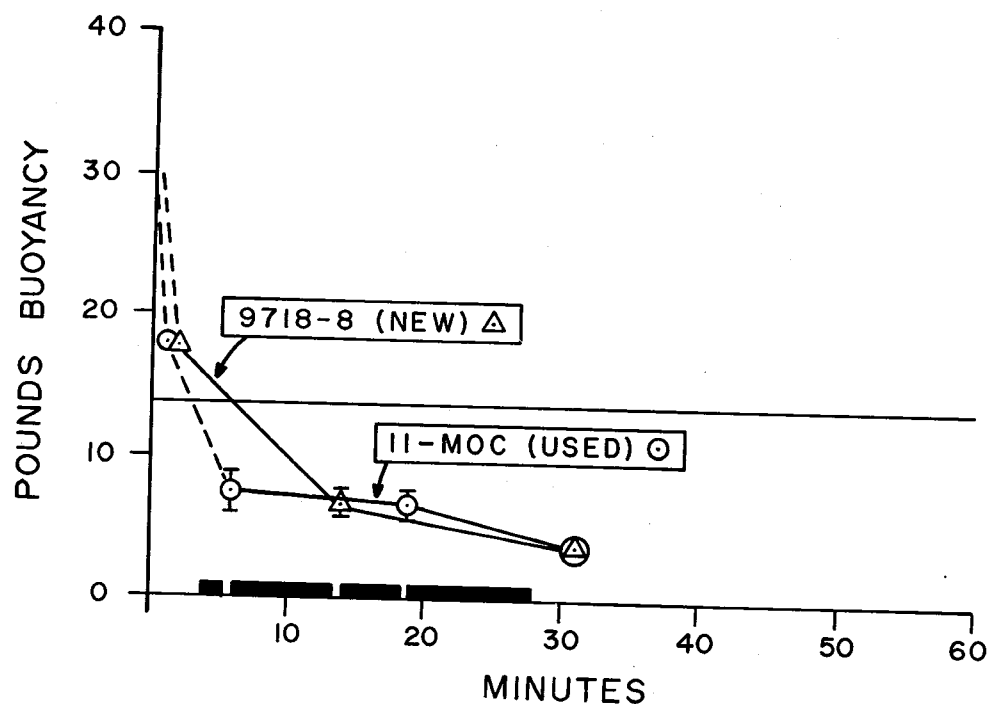


FIGURE A3. Dynamic seat-cushion test conducted on January 9, 1964, in the CARI 40- by 40-foot survival tank by human subjects wearing flight suits and tennis shoes. Initial and final measurements obtained by tension technique. Intermediate values obtained by use of lead weights. Lower bracket ⊥ indicates weight cushion would support and upper bracket T weight that produces sinking of cushion.

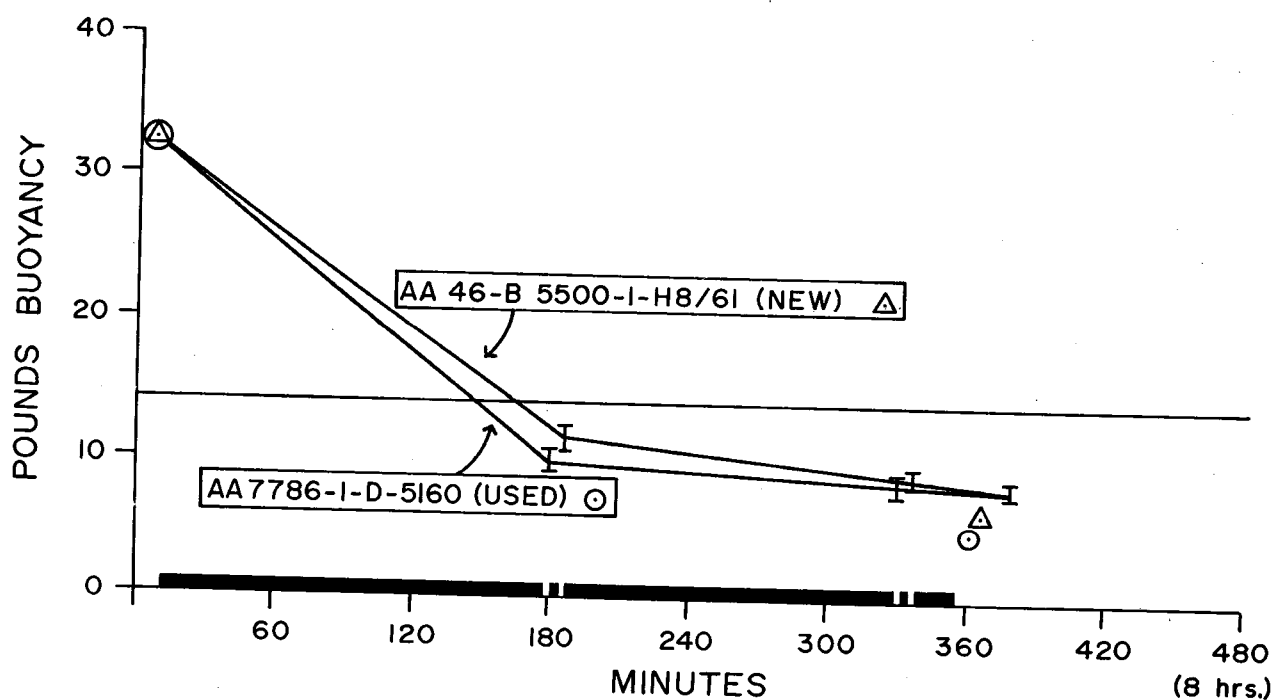


FIGURE A4. Dynamic seat-cushion test conducted on January 8, 1964, in CARI survival tank. Technique same as Figure 3. Lower horizontal portion of bracket ⊥ indicates weight cushion supported. Upper T indicates the weight that caused failure (sinking) of cushion. Both cushions tested simultaneously. Subjects were relieved hourly by new subjects during the test. Bar at lower edge of graph indicates time cushion in water and being used for flotation by subjects.

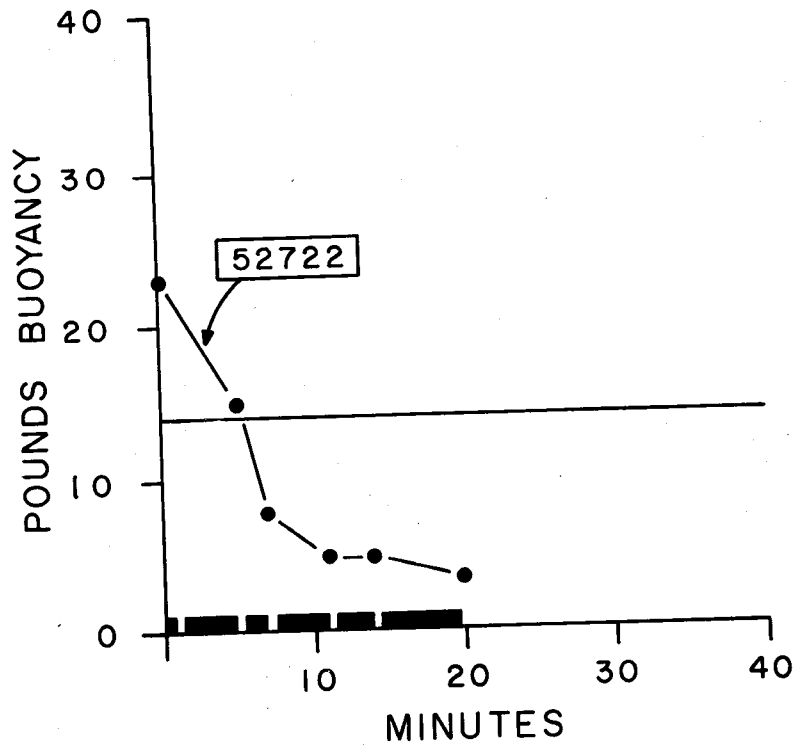


FIGURE A5. Dynamic seat-cushion test conducted on April 29, 1964, in CARI survival tank by human subjects. Initial and final measurements obtained by tension technique.

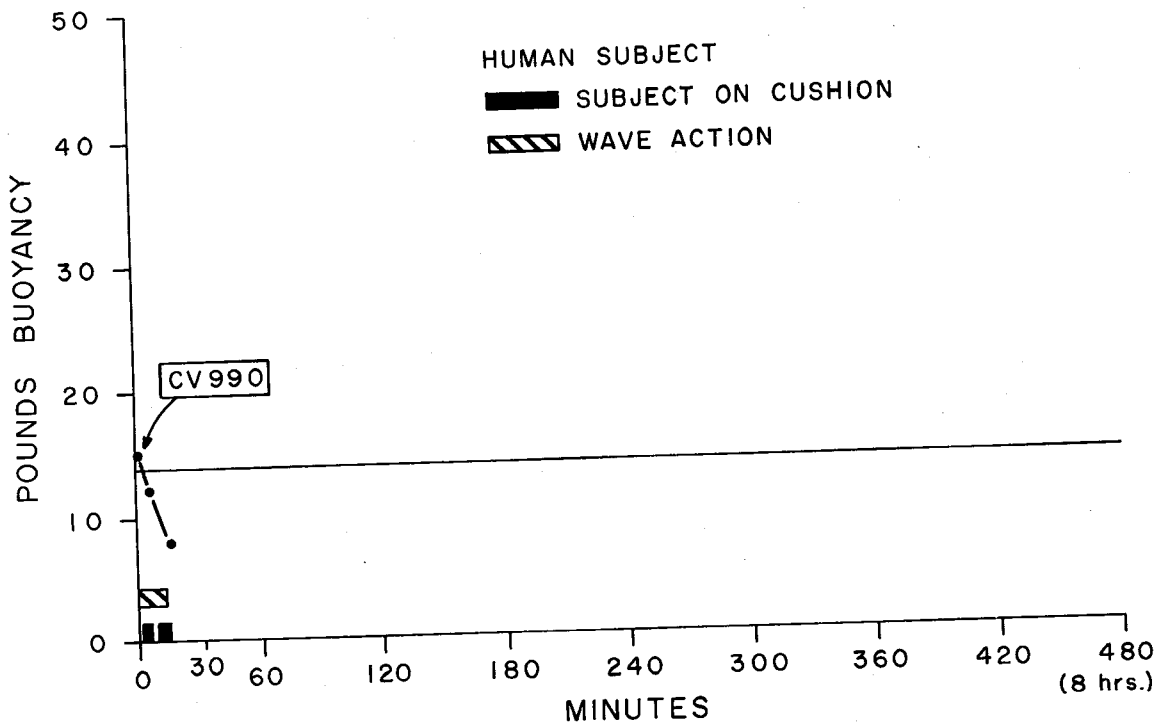


FIGURE A6. Dynamic seat-cushion evaluation conducted in February 1965 in survival tank under simulated wave conditions. CV-990 cushion not designed for flotation.

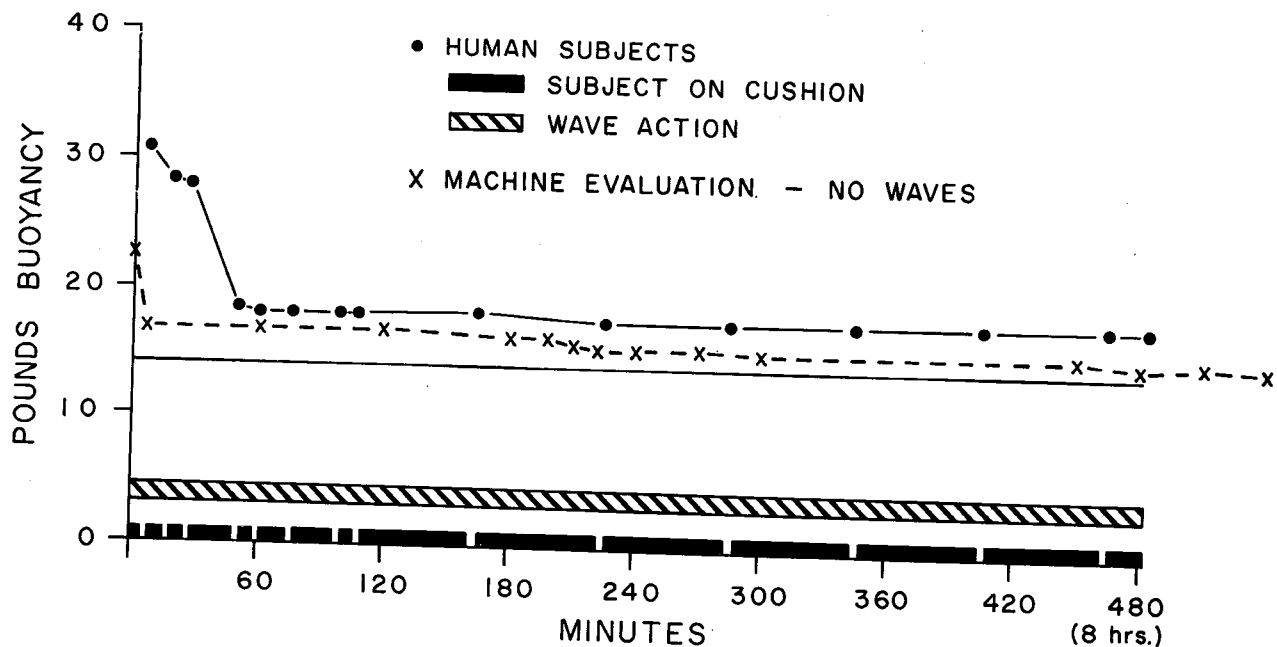


FIGURE A7. Dynamic field evaluation of a B. F. Goodrich experimental prototype multifoam 727 seat cushion conducted in July 1964 at Lake Tenkiller in open fresh water with moderate wave action. Machine test conducted in survival tank.

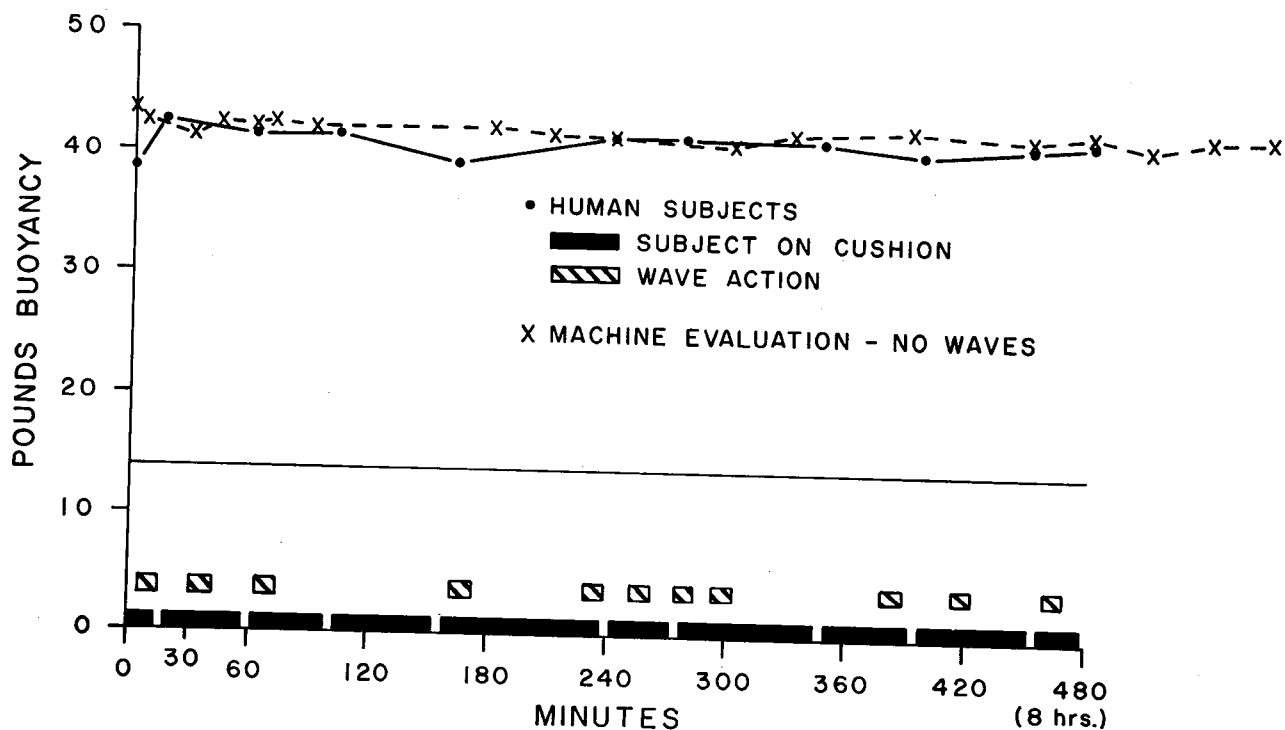


FIGURE A8. Dynamic seat-cushion evaluation conducted in February 1965 in survival tank. Standard Boeing 727 tourist seat-cushion polyurethane core encased in high-count linen cover with sealed seams. Waves $1\frac{1}{2}$ to 2 feet in height generated intermittently.

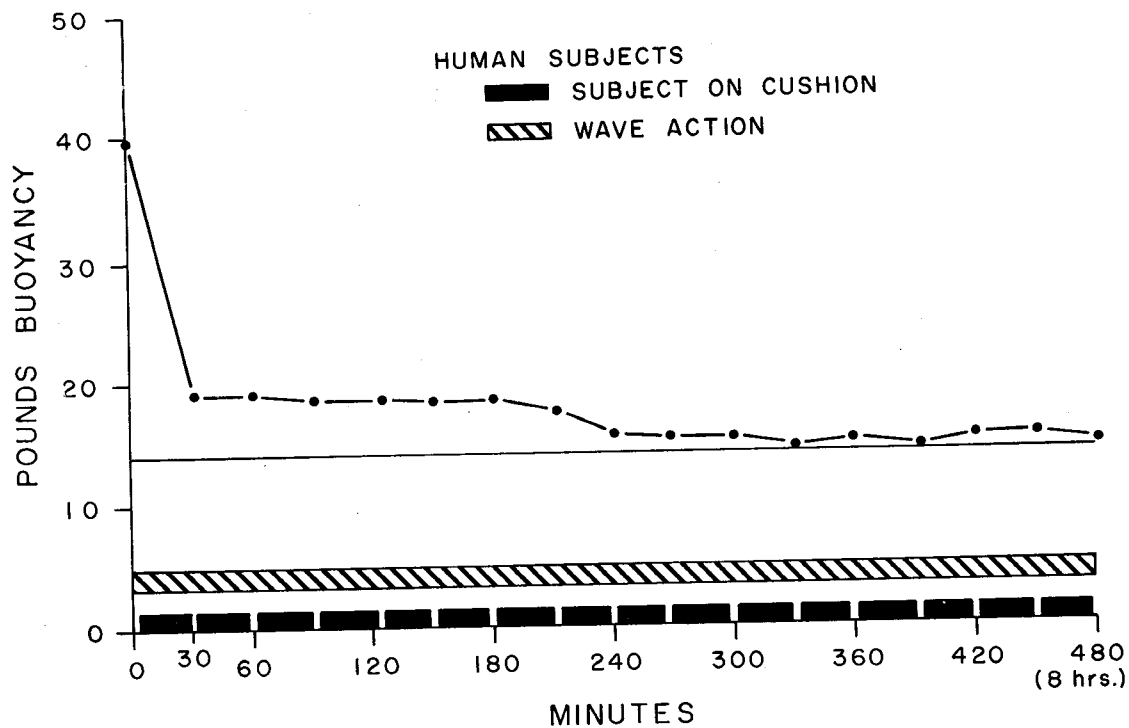


FIGURE A9. Dynamic seat-cushion evaluation conducted in January 1965 in the survival tank. Massey Company molded-foam crew seat cushion enclosed in high-count (hydrojac) cloth cover. Unsealed stitched seams, velcra closure. Waves 2 to 2½ feet in height generated during the test.

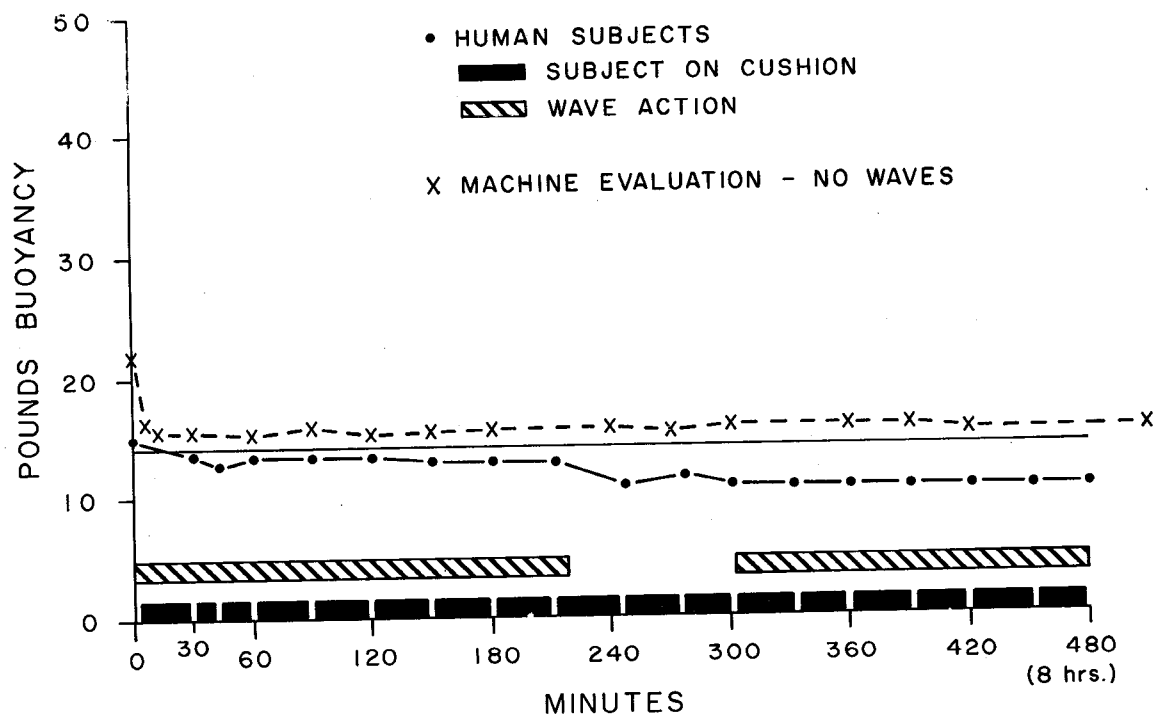


FIGURE A10. Dynamic seat-cushion evaluation conducted in January 1965 in the survival tank. B. F. Goodrich experimental multifoam tourist seat cushion. Waves 2 to 2½ feet in height. Water temperature 87°F.

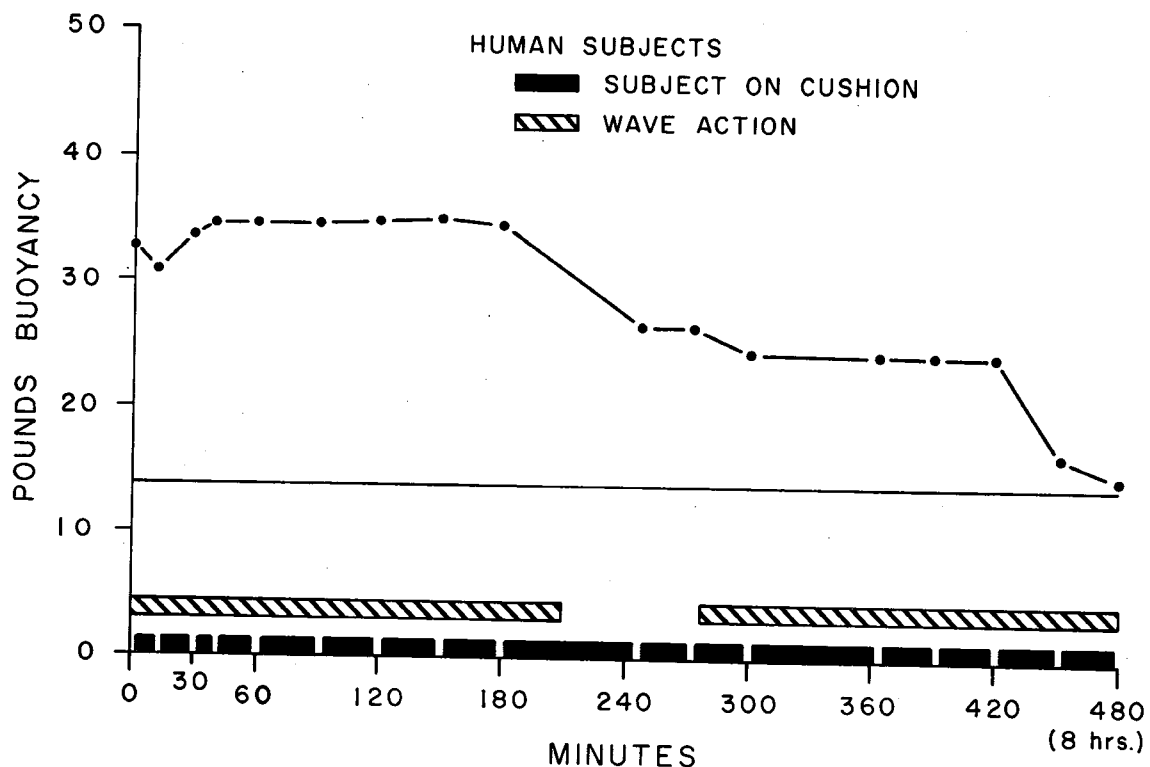


FIGURE A11. Dynamic seat-cushion evaluation conducted in February 1965 in the survival tank. Boeing 727 cushion encased in a close-weave linen cover with sealed seams.

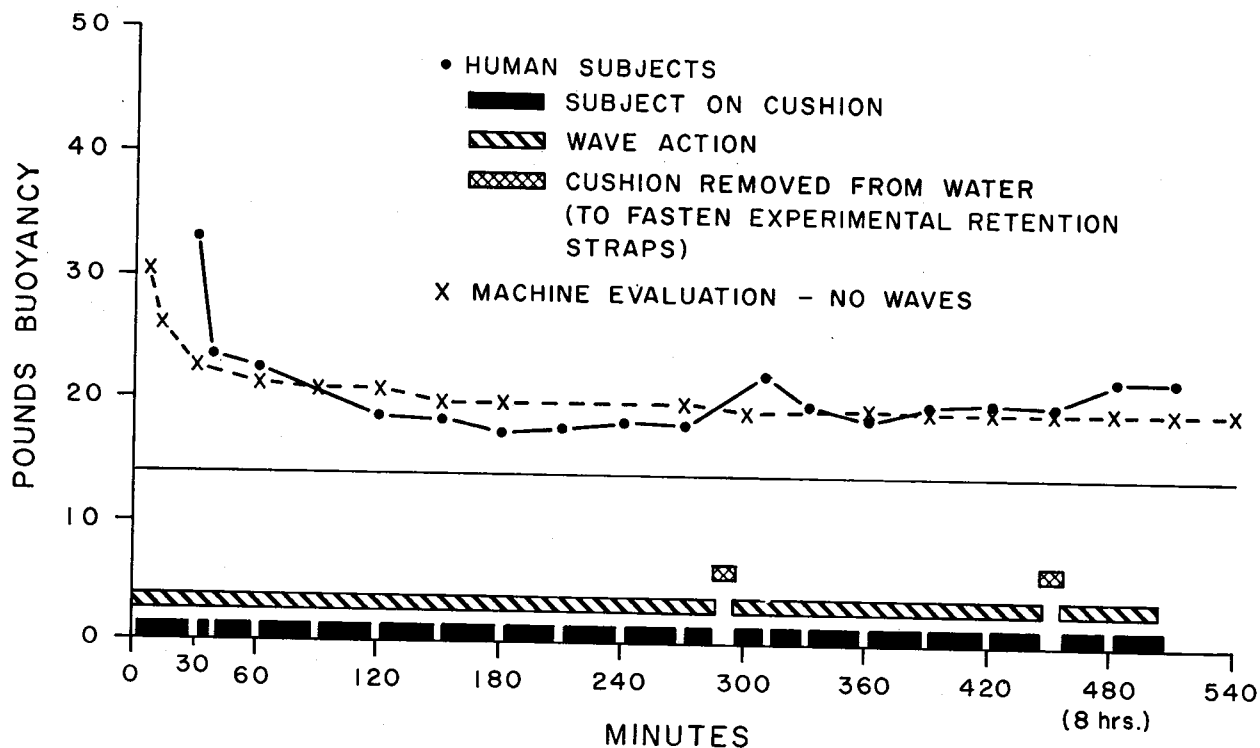


FIGURE A12. Dynamic seat-cushion evaluation conducted in February 1965 in the survival tank. B. F. Goodrich multif foam crew seat cushion. Blue-canvas stitched unsealed cover. Waves 2 to 2½ feet in height.

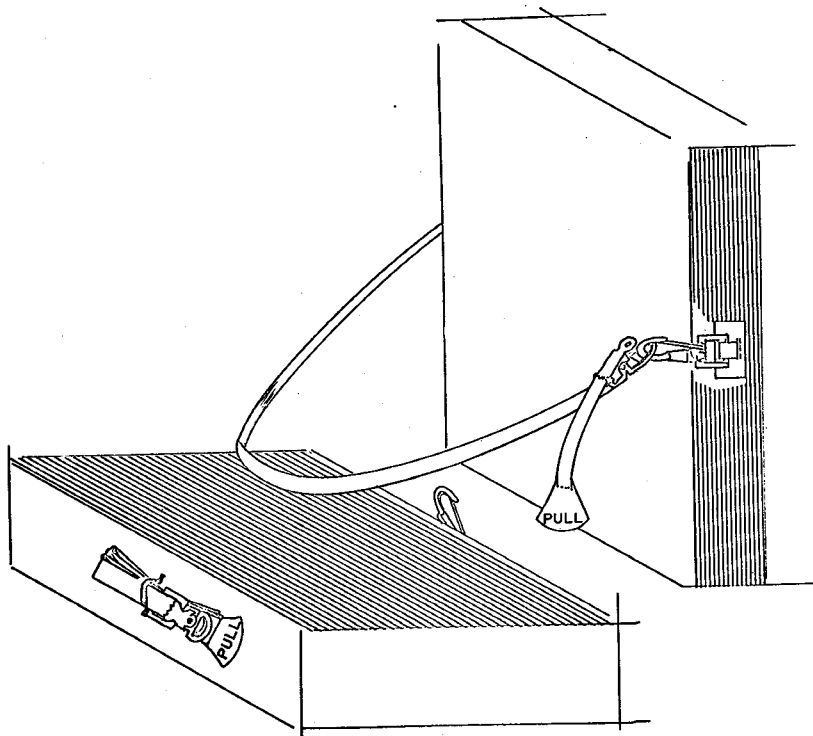


FIGURE A13. Diagram of a simple retention design utilizing life-preserver hardware.

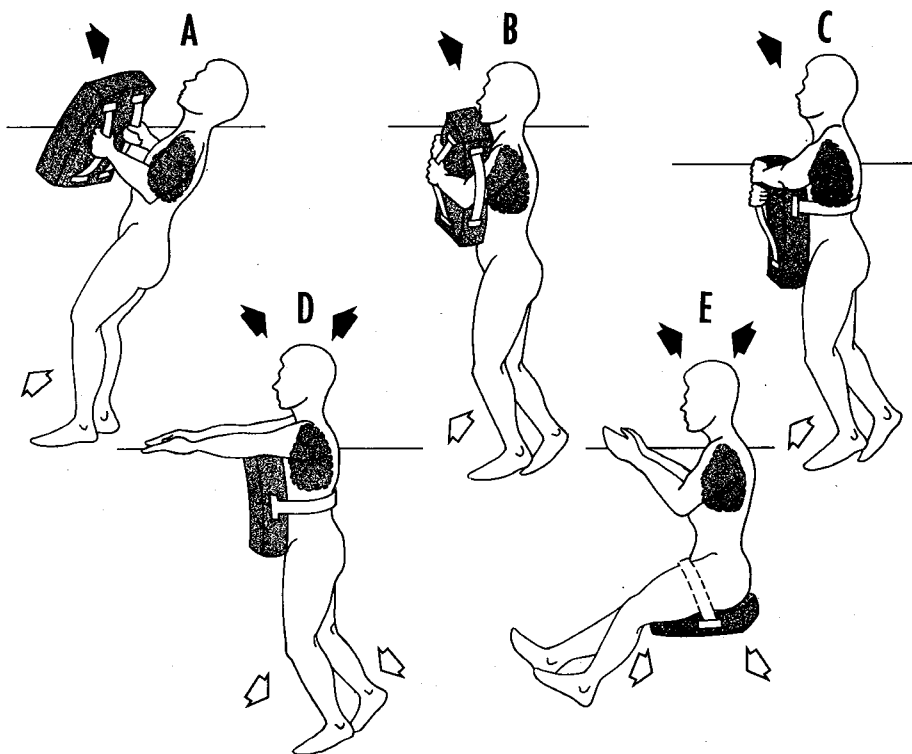


FIGURE A14. Flotation attitudes of the relaxed motionless subject as induced by the retention device and relative position of the cushion. Arrows indicate the direction in which the subject has a tendency to rotate.

APPENDIX B

After the appropriate weight in air was obtained, the subject was positioned in an underwater chair that was suspended from a balance. The water level was adjusted and a preliminary underwater weight of the subject was obtained. The subject then submersed, made a maximum exhalation, and turned the air-control valve to the spirometer position. The subject then made three maximum inhalations and exhalations, after which the air-control valve was turned from spirometer to snorkel position. After the final weight was obtained, the subject emerged and a tare of the chair and breathing hose was obtained. Nitrogen analysis of the spirometer air was accomplished with a Med-Science Electronics Nitralizer 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 and body density were calculated as follows:

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

VR=residual volume of lungs

V=volume of spirometer and hose

N₁=fraction of nitrogen in end-expired air before rebreathing

N₂=fraction of nitrogen in end-expired air after rebreathing

P₁=barometric pressure

P₂=partial pressure of water vapor in spirometer before rebreathing

T=temperature in spirometer before rebreathing

47=partial pressure of water in lungs

310=absolute temperature in lungs

55=dead space in valve and mouthpiece

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

D₁=body density

M₁=weight of subject in air

M₂=weight of subject under water

D₂=density of water at time of water

V_R=residual volume of lungs

TABLE B1. Human body density, mass, and residual lung volume of participating subjects

Subject	Sex	Body density*	Body mass in air (gm)*	Underwater body mass (gm)*	Residual lung volume (cc)
J. T.	M	1.0662	63,143	3,310	1,285
B. H.	M	1.0541	74,890	3,060	1,219
J. B.	M	1.0524	74,200	2,900	1,222
D. D.	M	1.0489	57,880	1,850	1,187
D. R.	M	1.0428	81,630	3,150	675
D. B.	M	1.0341	79,380	2,000	1,091
A. A.	M	1.0336	85,750	2,200	1,092
J. G.	M	1.0266	70,270	800	1,388
E. M.	M	1.0224	99,550	1,850	925
E. P.	M	1.0201	88,290	900	1,322
J. H.	F	1.0184	60,940	500	966
J. J.	M	1.0183	74,860	900	894
J. S.	M	1.0161	101,620	1,000	1,285

*Body density and mass includes clothing worn.