THE DESIGN OF LIFE-JACKETS

BY

E. A. PASK, M.D., D.A., F.F.A.R.C.S.

Professor of Anaesthetics, University of Durham

The properties of a serviceable life-jacket are various and depend upon the particular circumstances of use. Special needs impose special requirements. For example, a commando-soldier may carry much heavy metal equipment and may therefore need great additional buoyancy. A log-roller may be likely to be knocked unconscious as he falls into the water. Certain air-crew may be especially likely to be injured as they become cast-away.

Requirements

It is therefore difficult to generalize about life-jackets, but the following is an attempt. (1) A useful life-jacket should provide enough buoyancy to support a human being on the surface of fresh water. (2) The life-jacket should be easy to put on or should be so compact that it can conveniently be worn during periods of risk. (3) The life-jacket should be resistant to deterioration due to storage in various climatic conditions or to the stresses of use and misuse. (4) If possible, the life-jacket should allow the wearer to "swim" easily. (5) If possible, the life-jacket should support a weak or helpless man so that his mouth and nose remain clear of water without effort on his part.

The last of these requirements is probably of the least general importance, yet it gives rise to most discussion and argument.

Floating Position

There is emotional resistance to the thought of a life-jacket which tends to force the face under the water and which has to be countered by the activity of the cast-away. This aspect of the matter has received attention in the lay press.¹

The International Convention on Safety of Life at Sea (1960) (Regulation 22)² "requires that a life-jacket shall not be approved unless it satisfies the following requirements: (c) It shall be so constructed as to eliminate so far as possible all risk of its being put on incorrectly, except that it shall be capable of being worn inside out. (d) It shall provide support to the head so that the face of an unconscious person is held above the water with the body inclined backwards from its vertical position. (e) It shall be capable of turning the body, on entering the water, to a safe floating position with the body inclined backwards from its vertical position."

The main reason why this matter of the floating position has caused so much discussion is that it is difficult to bring it to objective test. It is quite easy to determine, objectively, the total buoyancy of a life-jacket. It is fairly easy to determine its resistance to compression and abrasion or the effect of temperature, humidity, and micro-organisms upon its performance. Whether or not a life-jacket easily supports a person without effort on his part, in a safe position in rough water, remains a matter of opinion, and thus of argument.

In an attempt to overcome this lack of objectivity, Macintosh and Pask³ made the assumption that if a life-jacket would support an inert, flaccid, unconscious man

in a favourable way, it should also support a weak man in a good position, while requiring from him the minimum of exertion. They used, as their test object, a rather deeply anaesthetized man. The limitations of the technique were recognized. Such experiments cannot be carried out in real sea conditions, and only very few subjects could ever be tested. The subject used in Macintosh and Pask's tests was of a particular body build, not necessarily representative of the "median man." In their discussion they wrote:

"The design of jackets so that they are comfortable, buoyant, robust, easy to inflate and adjust, able to carry ancillary equipment, etc., and yet allow the subject to swim, is properly the task of engineers.

"The engineer needs medical assistance, however, because the human body contributes most of the buoyancy to the subject/life-jacket combination, so that the body's variations must be considered.

"If dummies could be made, representative of the various types of men, women, and children, they would be of great help to engineers interested in this work. The dummies would have to be correct in weight, in total and distributed buoyancy, in the location of centres of gravity, and in flexibility."

With the publication of W.A.D.C. Technical Report 55-159⁴ most of the data needed for the design of a "floating" dummy representing a 50-percentile man became available. In consequence of this publication, one or two firms in the United States manufactured moulds in which dummies could be cast to conform with the external measurements of the man whose major dimensions are midway between the extremes of size, and many dummies have been made for use in tests of aircraft equipment and for the investigation of car crashes.

The existing dummies of this 50-percentile man were in no sense designed to float as a man does. However, the existence of the data and of the moulds based upon it made feasible the construction of a "floating" dummy.

The Dummy

It is difficult to know how accurate such a dummy need be in order to be of service. It was therefore decided to make the first dummy as accurately as possible, despite the high cost. The following requirements were agreed.

1. Limb and trunk segments should conform to the correct external dimensions and have densities conforming to the best available data. The data on body-segment densities in W.A.D.C. Technical Report 55-159 are mainly derived from experiments on dismembered corpses. However, the density of the body segments probably did not differ greatly from normal even though, through disease, the volume and mass of the segments may have been different from the figures for the 50-percentile man. The most difficult decision concerns the lung-containing segments of the body. The cadaver segment densities were accepted because they probably correspond to the state of an inert man who does not attempt respiratory activity or glottic closure and thus allows air to be forced from his lungs by the pressure of water on his abdomen and thorax. The thorax and upper abdomen will be more buoyant in active men, but experimentally this can be allowed for by adding buoyancy chambers.

2. The centre of gravity of each body segment should be correctly placed. It was decided that the distribution

of mass within each segment should be as close to normal as possible. Thus it was decided that the skeleton of the dummy should approximate in density to bone and should be encased in "flesh" approximating to the density of human flesh. In dummies for other purposes strong and heavy steel skeletons had been used, and flesh parts were often of foam rubber. The skeleton for the floating dummy was accordingly constructed of plastic laminates, fibreglass, and a minimum of stainless steel at articulations (Fig. 1). The consequence of deciding the size and shape and density of each individual body segment, and then assembling them into a dummy, was that the total mass and total volume of

FIG. 1

FIG. 2

FIG. 1.—Skeleton for floating dummy. FIG. 2.—The completed dummy.

the dummy would conform with known measurements from living men only if the predictions of segmental densities were reasonably correct. The design densities and the actual densities achieved are shown in Table I.

TABLE I.—Design and Actual Densities

Body Segment	Design Density	Actual Density	Design Percentage of Total Body Mass	Actual Percentage of Total Body Mass
Head	1.11	1.14	8.4	8.1
Upper arm ..	1.07	1.08	3.46	3.46
Forearm	1.12	1.13	1.61	1.61
Hand	1.12	1.13	0.54	0.54
Thigh	1.05	1.05	13.65	12.0
Leg	1.08	1.09	{ 4.65	6.5
Foot			{ 1.25	
Thorax	0.85-0.90	0.87	{ 41.3	{ 19.4
Abdomen and pelvis	1.05	1.05		

3. The range of movement of joints should permit all physiological movements and it should be possible to render the dummy quite flaccid or, alternatively, to apply tension to the joints so that conditions of rigidity of the body could be simulated, if necessary. The design range of joint movements is set out in Table II. In order to achieve spinal flexibility the dummy has six fibre-glass vertebrae in the cervical region and six in the

lumbar region. The friction between these vertebrae can be adjusted by a tension cable within them. Some slight compromise with reality has been accepted in that the rib-cage zone is rigid, in order to allow a watertight instrument compartment to be built within it.

TABLE II.—Design Range of Joint Movements

Head relative to trunk ..	Flexion forward ..	60°
	Flexion backward ..	60°
	Rotation to either side ..	60°
	Rotation ..	85°
Arm at shoulder	Flexion ..	180°
	Extension ..	80°
	Abduction ..	145°
	Rotation ..	100°
Forearm at elbow	Flexion ..	145°
	Extension ..	2°
	Supination/pronation ..	180°
Hand at wrist	Flexion ..	90°
	Extension ..	60°
Thigh at hip	Flexion ..	145°
	Extension ..	45°
	Abduction ..	70°
	Adduction (cross legs) ..	45°
	Rotation ..	50°
Leg at knee	Flexion ..	145°
Foot at ankle	Flexion ..	75°
	Extension ..	45°
Spine	Forward ..	45°
Rib-cage and shoulders in relation to pelvis	Backward ..	30°
	Rotation ..	50°
Shoulders in relation to rib-cage ("clavicular movement")	Down ..	5°
	Up ..	35°
	Forwards ..	20°
	Backwards ..	20°

4. It was required that the various properties of the dummy should remain as constant as possible, despite storage and repeated exposure to fresh or salt water. Two methods of construction seemed possible. First, to use any convenient materials, whether resistant to sea-water or not, and then to encase the dummy in an impervious skin to protect its interior parts. The second method was to use for skeleton and flesh parts materials which are inherently resistant to sea-water and thus to dispense with the need to rely upon the integrity of an impermeable skin. The second method seemed more reliable, and was chosen. The appropriate skeletal member was carefully weighed and then placed in position in the appropriate mould. It was then encased in polyvinyl moulding-compound of a density calculated to achieve the correct mean density for the segment.

Results Achieved

The densities planned and the densities achieved for each body segment are set out in Table I. The range of joint movements specified in Table II has also been achieved.

In total volume and total mass the dummy is a little smaller than was planned, being 93% of the volume and mass of the 50-percentile man. In other words, the dummy is of the proportions of the 50-percentile man, but he is about 7% smaller. By design the dummy should have weighed 165 lb. (74.8 kg.) and should have displaced 151 lb. (68.5 kg.) of water when immersed to a depth of 60 in. (152 cm.). In fact, the dummy weighs 153 lb. (69.4 kg.) and displaces 140 lb. (63.5 kg.) of water when immersed to 60 in. (152 cm.). Table I also shows the percentage mass of the body segments to which the dummy was designed and the percentage masses of the dummy's actual body segments. These figures should be regarded with some reserve, because the dummy cannot be dismembered in precisely the planes used to define the body's segments. In particular, the dummy is necessarily so constructed that a segment of buttock remains attached to the trunk, which, in accordance with the plane used to define the division, would appertain

to the thigh. Thus the dummy's trunk mass appears somewhat increased and the thigh mass a little reduced.

The reasons why the dummy is a little smaller and lighter than the 50-percentile man are almost certainly two. First, the moulding compound used for flesh has to be poured into the moulds at high temperature. Some expansion of the skeleton would occur at these temperatures, so that the mould would not permit the entry of exactly the calculated volume of "flesh." Contraction of the skeleton and consequently also of the flesh moulding would occur on cooling. The second reason is that, because of the form of construction, all joints contain open cavities into which water can penetrate on immersion. Such cavities can hardly affect buoyancy, since on immersion they become filled with water which approximates to the density of the dummy, but they do appear as deficiencies of volume when this is measured by immersing the dummy in water. The loss of weight of the 50-percentile man as he is progressively immersed in fresh water up to the 60-in. (152-cm.) level has been calculated. The values have been reduced by the fraction 93/100, since it is known that the dummy is smaller in this proportion. These values are plotted as the continuous line in Fig. 3, in which the actual values obtained by progressively immersing the dummy are shown by dots. The volume centroid of the whole dummy is at 38½ in. (97.8 cm.) from the feet, and this agrees with the 50-percentile man.

FIG. 3.—Weight loss of 50-percentile man as he is progressively immersed in fresh water.

Centres of Gravity of Segments.—The centre of gravity of each limb segment has been determined and related to the planes cited in W.A.D.C. Technical Report 55-159. The centres are, in all cases, within 2% of the correct positions. The centre of gravity of the whole dummy is 37½ in. (92.7 cm.) from the feet, and this conforms with the 50-percentile man. Fig. 2 shows the completed dummy.

Behaviour of the Dummy.—So far the dummy has been tested only in still fresh water. Without any extraneous buoyancy the dummy sinks, feet slightly first, in a manner reminiscent of the behaviour of the anaesthetized subject used by Macintosh and Pask.³ When wearing a wartime R.A.F. Mae West the dummy floats in a 45-degrees face-upwards position, as did the anaesthetized man. When the dummy, wearing the Mae West, is deliberately placed face downwards and horizontal on the surface of the water, it rights itself by a combined tilting and twisting movement as did the anaesthetized man. Macintosh and Pask found that a particular buoyant suit which added buoyancy over all body segments caused the anaesthetized subject to float in a stable manner, either face up or face down, depending on how he was placed. The dummy behaves similarly.

Discussion

An attempt has been made to construct a dummy which resembles as closely as possible an inert man in those properties which may be expected to affect the position in which a man would float when supported by life-saving gear. If the dummy becomes accepted as a test-object it is hoped that the orientating properties of life-jackets may in future be determined in a more objective and less time-consuming manner than in the past. It is also hoped that the existence of such a test-object may enable marine architects more easily to study the problems of life-jacket design. The dummy is soon to be used for tests of life-preserving gear in real sea conditions.

If the dummy, representative of the 50-percentile man, becomes accepted it may be necessary to attempt to construct 5-percentile and 95-percentile dummies of men and perhaps also to study the problems involved in making dummies representative of women and children. The dummy may also be useful for the study of such physical problems as the vertical accelerations to which a man is subject when floating in various life-jackets, the rate of heat loss when various forms of protective clothing are used, and the rate of drift of castaways in various sea conditions. This dummy has been made as accurately as possible in accordance with the available data. It is uncertain how great a degree of accuracy is necessary in practice. Simpler and cheaper dummies can now be made and their performance compared with this prototype.

Summary

A dummy has been constructed which resembles an inert man in those properties which may be expected to influence floating in water. It is believed that the dummy will be useful in the design and testing of life-preserving gear.

The construction and dimensions of the dummy are described.

This project has been made possible by a generous grant from the Sir Halley Stewart Trust. Preliminary inquiries were supported by Messrs. P. Frankenstein & Sons Ltd. The dummy was constructed by the Sierra Engineering Corporation of California. Their generous interpretation of the terms of their contract has been most helpful. The dummies constructed by this firm are usually nicknamed "Sierra Sam," and this one, not surprisingly, is known as "Seaworthy Sierra Sam." The R.A.F. Institute of Aviation Medicine greatly assisted in the initial trials, and the Royal National Life-Boat Institution has made possible the sea trials at present in progress.

REFERENCES

- ¹ *Daily Telegraph and Morning Post*, July 25 and November 9, 1960, and March 21 and 30, 1961.
- ² International Conference on Safety of Life at Sea; Final Act. H.M.S.O., London, 1960.
- ³ Macintosh, R. R., and Pask, E. A. *Brit. J. industr. Med.*, 1957, 14, 168.
- ⁴ "Space Requirements of the Seated Operator," by W. T. Dempster. Wright Air Development Centre, 1955. W.A.D.C. Technical Report 55-159.

The Ministry of Health has sent a memorandum to Regional Hospital Boards, Hospital Management Committees, and Boards of Governors drawing the attention of hospital authorities to the need for employing more part-time nurses and midwives. The memorandum makes suggestions on the recruitment, reception, welfare, hours of duty, and refresher training of such part-time staff as well as for their introduction into the hospital life and work.