The Man In The Aqueous Element

A contribution to the problem of life-preservers

By

JOST B E R N H A R D T, Hamburg

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For the safety of life at sea a large number of implements' devices have since been invented and put into use. In certain cases of distress, the life-preserver is of vital importance and sometimes such an individual saving device offers the only means to the wrecked person to survive afloat the time following the shipwreck.

In any case, the body of the floating person has to be supported by the buoyant elements of a life-preserver, no matter, whether the person is capable to swim or not, whether he is weak or exhausted or even unconscious.

Can life-jackets or life-preservers meet this requirement at all events ? The following aims to comprehend the hydrostatic properties of the human body floating in water. Relating historical researches and their findings are already known which will, however, only be touched in this report while the historical development of life-preservers throughout the ages will be the exclusive subject of another paper to be published shortly.

The uninterrupted inhalation of atmospheric oxygen represents the irrevocable condition to a man to keep alive in the aqueous element. Thus, the man is placed into a transitional situation between atmosphere and water since his breathing orifices (nose and mouth) must remain in the atmosphere.

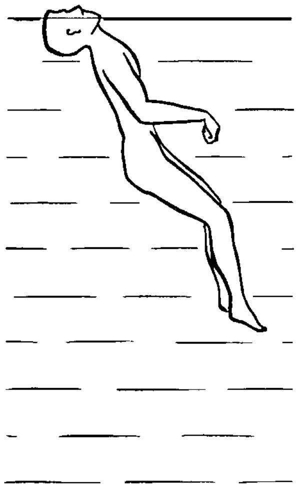
Therefore, a well-constructed life-preserver must at all events keep the mouth and nose of the victim clearly out of water, independently from a possible additional buoyancy produced by natatorial movements. The testing of these requirements have necessitated various researches and considerations.

In a voluminous paper entitled 'System of the art of swimming', issued in 1794, the abbot PAOLI MOCCIA reported on the specific properties of the human body in the water. A large number of experiments and observations were described. MOCCIA was inspired to write on this subject as he himself was able 'to walk correctly in the water' which he did sometimes even coram populo, this phenomen not being amazing since the abbot was said to be rather corpulent.

According to MOCCIA, extensive experiments were carried out by BORELLI and ALTIERI - independently from each other - who immersed volunteers into overflow receptacles and thus found that the specific gravities of the individuals differed and that the majority of the persons were specifically lighter than water. If in spite of this fact many people would still be drowned, they argued, this would be caused by awkward actions and movements and by ignoring the fact that the water itself be capable to support the body.

In the second half of the 18th.century ORONZIO DI BERNHARDI reported also on 'The art to learn swimming' and that without auxiliaries, such as cork, bladders, rush, bottles and the like, He stressed the importance of giving the confidence to people that the water be capable of supporting the body sufficiently, and that the limbs be much lighter in the water than in the atmosphere. At that time, however, it was rather difficult for the critical observer to check upon the truth of such an assertation which is the reason why these theses were impeached unjustificatorily.

Nowadays, we know by experience from bathing that a person of normal physique, afloat with half-filled lungs, can keep his mouth and nose just above the surface without exercising additional natatory movements (Fig. 1).



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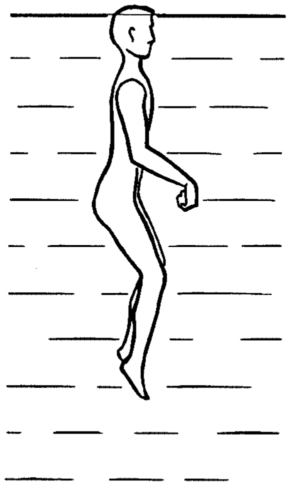


Abb. 2

During the exhaling phase the body will sink.

A specifically light person, i.e., a corpulent one, can inhale and exhale in the position described above without fear to get his breathing orifices immersed, while, in general, a specifically heavy person can just maintain a floating position with full lungs only.

Apart from these specific constitutional characteristics, the static buoyancy is also influenced by the varying breathing capacity of the individuals.

The range in anatomic-physiological respect and between the residuum of the lungs (fully exhaled) and their vital capacity (fully inhaled) may be assumed to be as average 3 dm^3 (litres) which in water is equal to a buoyancy of 3 kg.

In the following, however, this range should not be considered nor the questions of the difference in buoyancy between salty and fresh water and between clothed and unclothed persons, in order to concentrate on the principal and elementary hydrostatic conditions.

We may proceed from a person of normal physique and normal specific conditions who floats in an assumed position (Fig. 2).

The weight of the total body is equal to its buoyancy, i.e.,

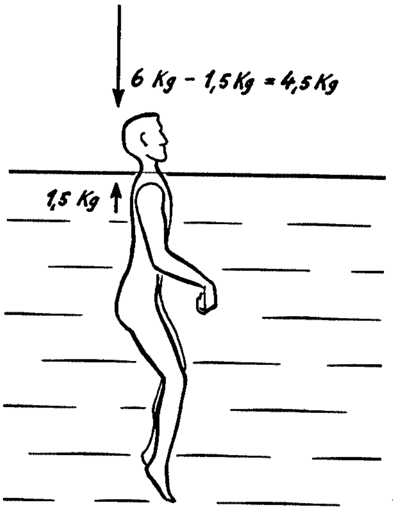
$$P = A$$

$$P_{body} + P_{head} = \gamma \cdot (V_{body} + V_{head}) + A_f$$

As already pointed out before, it is indispensable for keeping the floating person alive that his head, and consequently his breathing orifices, be maintained out of water, and that to such extent that they will not be reached by small waves (Fig. 3).

Considering the head's weight to be approx. 6 kg and its volume to be approx. 4.5 dm^3 (litres), it follows that the fully immersed body must have an additional buoyancy of 1.5 kg in order to be able to float freely according to Fig. 2 in spite of the specifically heavy head.

By this additional buoyancy of A_{free} = 1.5 kg the head's weight will, in fact, be reduced from 6 kg to 4.5 kg.



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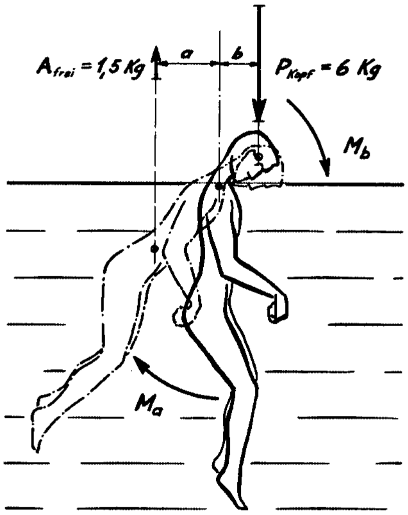

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Thus, a power of 4.5 kg will be required to keep the body in a Position like Fig. 3.

The relating formula is as follows:-

$$P_{body} + P_{head} = \gamma \cdot (V_{body} + V_{head}) + A_{free} + A_{required}$$

Hereby, V_{head} will be equal to 0 since the head is out of water

$$A_{free} = A_f = P_{head} - \gamma \cdot V_{head} \quad \text{for the position of Fig. 2}$$

$A_{required}$ - in the present case 4.5 kg - will be the minimum of the buoyant force of a flotation gear to keep the head clearly out of water. Whilst swimming the buoyancy required to keep the person in a hydrostatic equilibrium will be produced by natatory movements, i.e., dynamically.

The obligatory position of the body in the water assumed hitherto is instable. In a relaxed body (in case of exhaustion or unconsciousness) due to the S-shaped curvature of the spine, the head will fall forward upon the chest with inflexion of the vertebra pointed to the front (Fig. 4). Thus, the weightvector P_{head} is exceeding the centre axis of the upright body, resulting in a tipping momentum:-

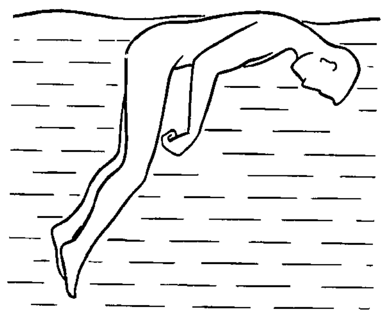
$$m_b = P_{head} \cdot b$$

This momentum causes the vector of the released buoyancy A_{free} to pass across the other side of the centre axis tipping under the influence of M_b, resulting in a rising momentum:-

$$M_a = A_{free} \cdot a$$

By these two momenta M_a and M_b, working in the same sense, the body is turned into a prone Position (Fig. 5).

The same effect will be observed with a fully immersed body according to Fig. 2.



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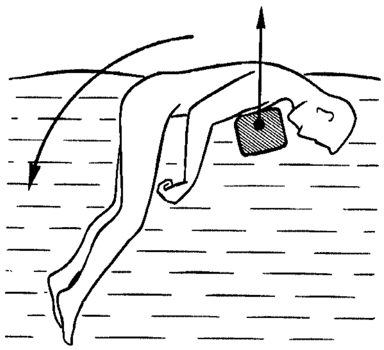

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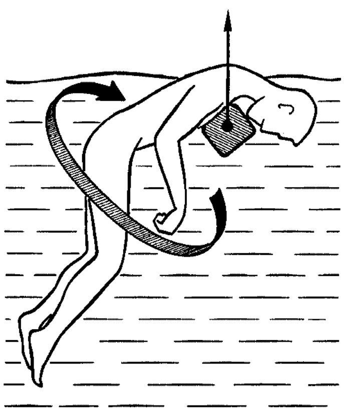

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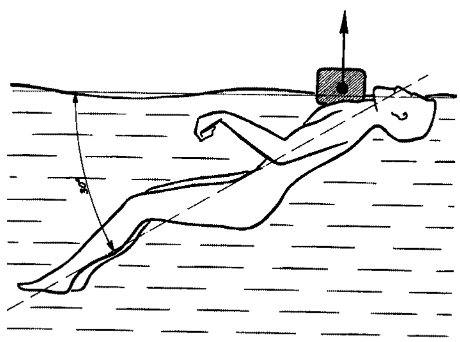

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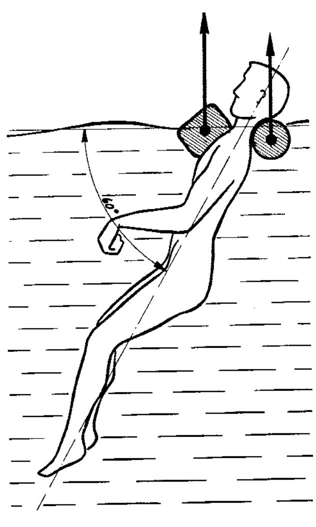


Abb. 9

With the lungs fully filled a part of the back will slightly protrude, and the body will be now in the hydrostatic equilibrium.

Being drowned a person will also reach this Position although in such a case, in the absence of the lungs' buoyancy, the breech will take the highest point. Dragging traces on the fore-head, the outer area of the hands, the knees and on the toes of drowned persons who touched the bottom are sufficient a proof for this typical position.

Apart from its proper buoyancy a flotation gear should also counteract this tipping tendency of the human body in the water.

A buoyant element placed above the chest lifts the upper part of the body while its lower part sinks slightly (Fig. 6).

In the endeavour to reach its buoyant equilibrium (Fig. 7) the buoyant element turns the body into a supine position (Fig.8)

By protruding above the surface a part of the buoyancy of the element is lost resulting in the head not protruding sufficiently. By a second buoyant element fixed in the person's neck, the head will be kept clear of water (Fig. 9) whereas this second element cannot hinder the head to tip laterally. Therefore, also a lateral support is indispensable (Fig. 10)-

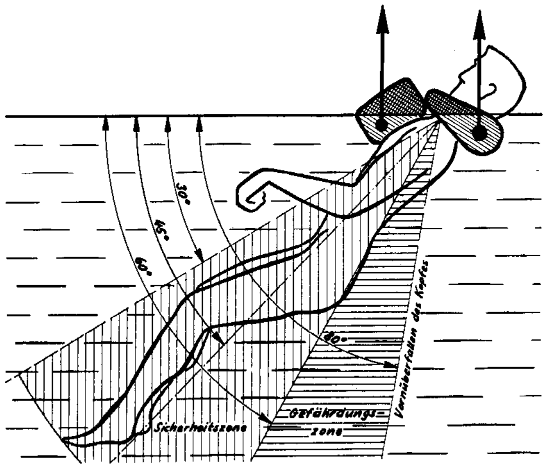


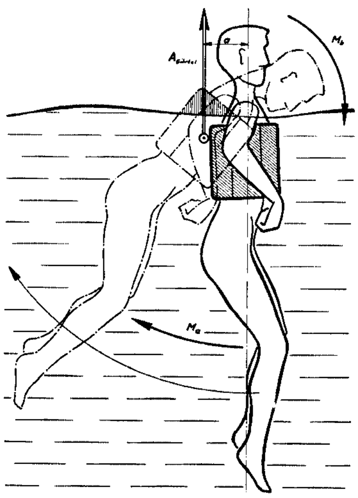
Abb. 10

The relation in the distribution of buoyancy in chest and neck has to be maintained accurately since otherwise, e.g., by too bulky a neck buoyancy pad, the body could be moved into a dangerous vicinity of the head's tipping point at approx. 80° resulting in the chest buoyancy pad - of too less bulk - being pressed down by the head's momentum, although the chest pad had been placed correctly in anatomical respect, in consequence whereof the body would be moved into a stable prone position.

The supine oblique posture of the body may vary only within a range from 30° to 60° notwithstanding the anatomic-physiological range of the physique, the additional buoyancy of the body in salt water, the kind of clothing as well as contents of pockets. Within the range stipulated the head will always tip backwards without immersing so far that nose and mouth be reached by small waves.

The normally required buoyancy ($A_{required}$) of 4.5 kg minimum, as stated above, will not be sufficient to guarantee the position like Fig. 10 considering the variable breathing capacity and the other variabilities mentioned above. Therefore, larger buoyant forces than 4.5 kg must become effective in a flotation gear.

The additional part of the buoyancy pads of a flotation gear required for the heaviest person within the aforementioned range



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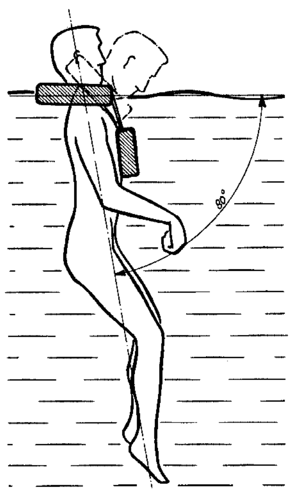


Abb. 12

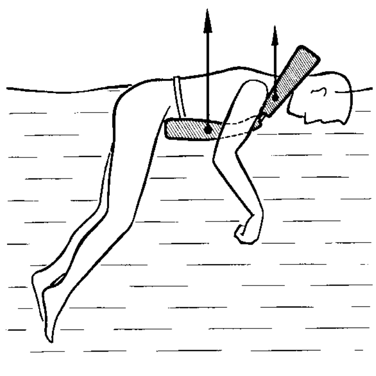
should protrude in case of a person of normal physique in the oblique supine posture (Fig. 10, chequered parts).

By this buoyant reserve the oblique supine posture must at all times be recovered after being disturbed by natatory or wave movements. The additional buoyancy as produced by natatory movements may avoid the oblique supine position, however, this stable position must be recovered again by the buoyancy pads of the flotation gear immediately after the natatory movements have been ended, e.g., in case of exhaustion and the like. The buoyancy elements must carry the body like a tumbler; the centre of buoyancy must automatically be placed again above the centre of gravity. The union-system of body-flotation gear must be maintained stabled.

In case of most of the life-jackets and life-belts of known a.nd usual construction the floating person is forced to exercise considerable powers all the time in order to keep the body balanced since the buoyant elements become effective at wrong places of the body the forces of which must be compensated by constant natatory movements.

In Fig. 11 a circular life-belt is shown which is in general use up to the moment.

A life-jacket of approx. 8 kg buoyancy lifts the head's weight of approx. 4.5 kg out of the water and, furthermore, lifts also a part of the shoulders of a weight of approx. 3.5 kg. Thus, the total weight of the parts lifted corresponds to the buoyancy of approx. 8 kg.



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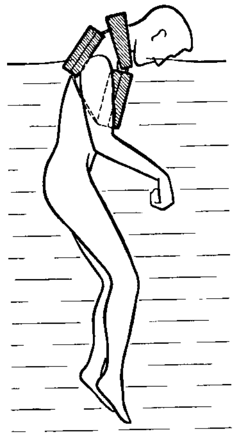

Abb. 14

The forward tipping momentum of the head becomes effective, the rising momentum of the trunk being even amplified by the life-jacket resulting in a stable prone position in case of exhaustion or unconsciousness, according to Fig. 4. This dangerous position can be avoided only by constant natatory movements.

Buoyant elements, though placed correctly in anatomical respect, do not warrant a stable supine trim positio7a unless the buoyant elements in both the chest and neck are bulky enoug to counteract the extreme forces within the physiological range.

Since the chest buoyancy is too small (Fig. 12) the stable oblique supine position cannot be ensured since the body may be moved into a vertical position of 80°. If, in this event, the body is pressed forward by waves it cannot be moved again into the stable oblique position by the chest buoyancy for its backturning momentum is not sufficiently large. In case, the chest buoyancy, though bulky enough, is placed too low (Fig. 13) it will not be able to right the body but will even stabilize the prone position if the person was moved-into this position by waves or swam with breast-stroke and then lost consciousness. A lateral turning will be hampered by the freely suspended arms which thus will add to the stabilization of this prone position.

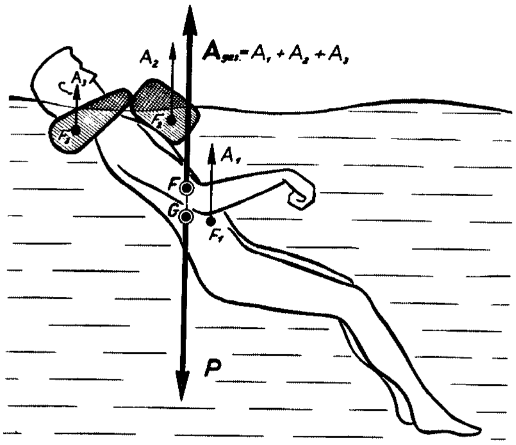

Abb. 15

Unless the chest buoyancy is of unusual bulk any back buoyancy or too bulky a neck buoyancy will avoid the oblique supine position and will, on the contrary, stabilize the fatal prone position (Fig. 14) even to a larger extent than shown in Fig. 13.

Summarizing the above it should be maintained that

1.) the buoyant elements provided in a flotation gear join with the bodyls buoyancy thus forming the total buoyancy, and become effective in their common centre of gravity F (Fig. 15),

2.) the centre of buoyancy must always lie exactly the centre of gravity, it must remain there and must recover this position, if disturbed, in order to warrant all the time and at all events the stable oblique supine trim position corresponding to the hydrostatic and biological conditions and requirements.

ABBREVIATIONS

P	=	weight (kg)
A	=	buoyancy (kg)
γ	=	specific gravity of water (kg/dm^3)
V	=	volume (dm^3)
M	=	momentum
F	=	centre of buoyancy
G	=	centre of gravity
P_{body}	=	weight of body excl. head
V_{body}	=	volume of body excl.head
Af	=	excess buoyancy of body transformed to A_{free} in case of head protruding out of water

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