Defence Science Journal, Vol. 1, No. 1, July 1949, pp. 1-9

THEORY OF LOAD CARRIAGE BY MAN.*

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Introduction.

Carrying of load by man has been a necessity since pre-historic times. It was the sole means of transportation prior to the domestication of animals like ox, ass, horse, etc. Today with the advancement of mechanical transport, the art has disappeared except where mechanical transport is beyond rearch, impracticable or uneconomical.

In the Army, too, the soldier used to carry on his back about 80 lbs., but with the advent of mechanical transport and its increased use and in order to allow more freedom for the soldier's energy to be available for combat, he is now made to carry about 40—50 lbs.

Load carrying by man in Mountain Warfare has assumed greater importance where mechanical transport cannot be employed and the use of mules is restricted due to sufficient numbers not being available. In high altitude fighting transport of equipment and weapons can be carried by man alone due to difficulty of terrain. In order, therefore, to carry the load effectively in mountainous terrain and particularly at high altitudes more efficiently :—

(a) methods have to be devised so that for a given output of energy a greater weight can be carried ;

(b) weapons and ancillary equipment can be so designed as to be capable of being carried easily by man.

Theory.

In determining the most efficient methods of carrying loads, certain mechanical factors have to be taken into account, the principles of which are :—

(a) Mechanical efficiency when standing (static) ;

(b) Mechanical efficiency when walking (kinetic).

Static efficiency.—When a man carrying load is standing still, both himself and the load are in equilibrium and certain forces are acting on the load. The two main forces acting are (1) the force of gravity of the load (2) the force exerted by the body on the load. For maximum efficiency the force of gravity of the load and force exerted by the body should be equal and opposite. But they are not always so. In fact, the body generally exerts greater forces on the load than its actual weight.

Kinetic efficiency.—When a man is walking at a constant speed, his kinetic energy is regulated to that speed, but no sooner than he changes his speed, rate of climb, or direction, simultaneously with these changes there is a change in kinetic energy. He must build up/break down the kinetic energy in the load accordingly and this

* Read at the Defence Science Conference, 1949.

is accompanied by expenditure of his bodily energy. For efficient load carrying, the expended energy should be reduced to the minimum.

These changes in energy can be divided into linear and angular. Provided the load carried is not eccentric to the direction of motion, linear changes will not be affected greatly by the method of carriage and packing. Angular changes, on the other hand, are affected considerably.

The point is best illustrated by considering a long body. (Fig. 1).

If such a body is to be rotated, it is obvious that it is easy to rotate it about the axis XX passing down its centre. It is more difficult to rotate it about axis YY, and most difficult to rotate it about any axis ZZ outside it and away from its centre of gravity. The rotations which occur in load-carrying will be resolved into rotations in three planes at right angles to each other :

(a) Rotation in a horizontal plane about the vertical axis; changes of direction in walking involve rotation in this plane.

(b) Rotation in a vertical plane passing from front to rear, about the horizontal axis situated outside the body. The flexion of the trunk which accompanies stepping up is an example of a movement which involves the rotation of a load on the back about this axis.

(c) Rotation in a vertical plane at right angles to (b) above about a horizontal axis. Rotation of this kind is involved in a lateral bending of the trunk, as in balancing.

The energy required to initiate rotation of a body around its axis is determined by the moment of inertia about the axis which is, in turn, proportional to the square of the radius of gyration. So, if it were possible to concentrate the mass at a point on the axis of rotation, the radius of gyration will be zero and consequently the energy required to stop or to produce rotation round that axis will be nil. But this really is not practicable in load-carrying.

In practical load-carrying, therefore the best results will be obtained by :—

(a) reducing the bulk of the load by careful packing;

(b) loading it length-wise along and as close as possible to the axis around which the body is most likely to rotate;

(c) placing the centre of gravity of the load as close as possible to the other axes of rotation as much as considerations of static efficiency permit.

It will be noted, therefore, that along a straight and level path, changes in angular momentum will be very little, but in rocky, rough, very circuitous paths, changes in angular momentum will be considerable and the kinetic factor will assume considerable importance, so much so that certain otherwise efficient methods of load-carrying may become impracticable.

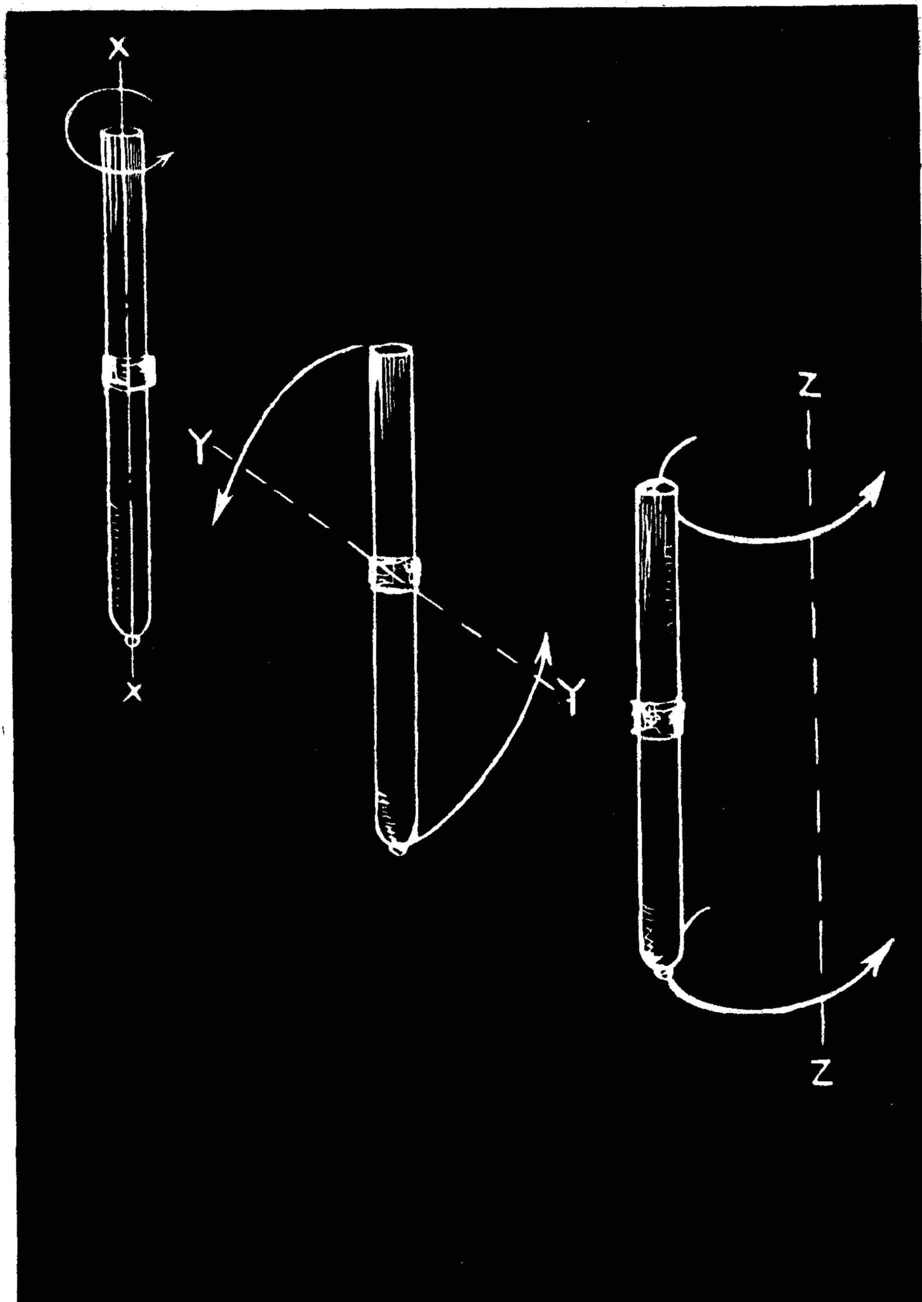

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Fig. 1

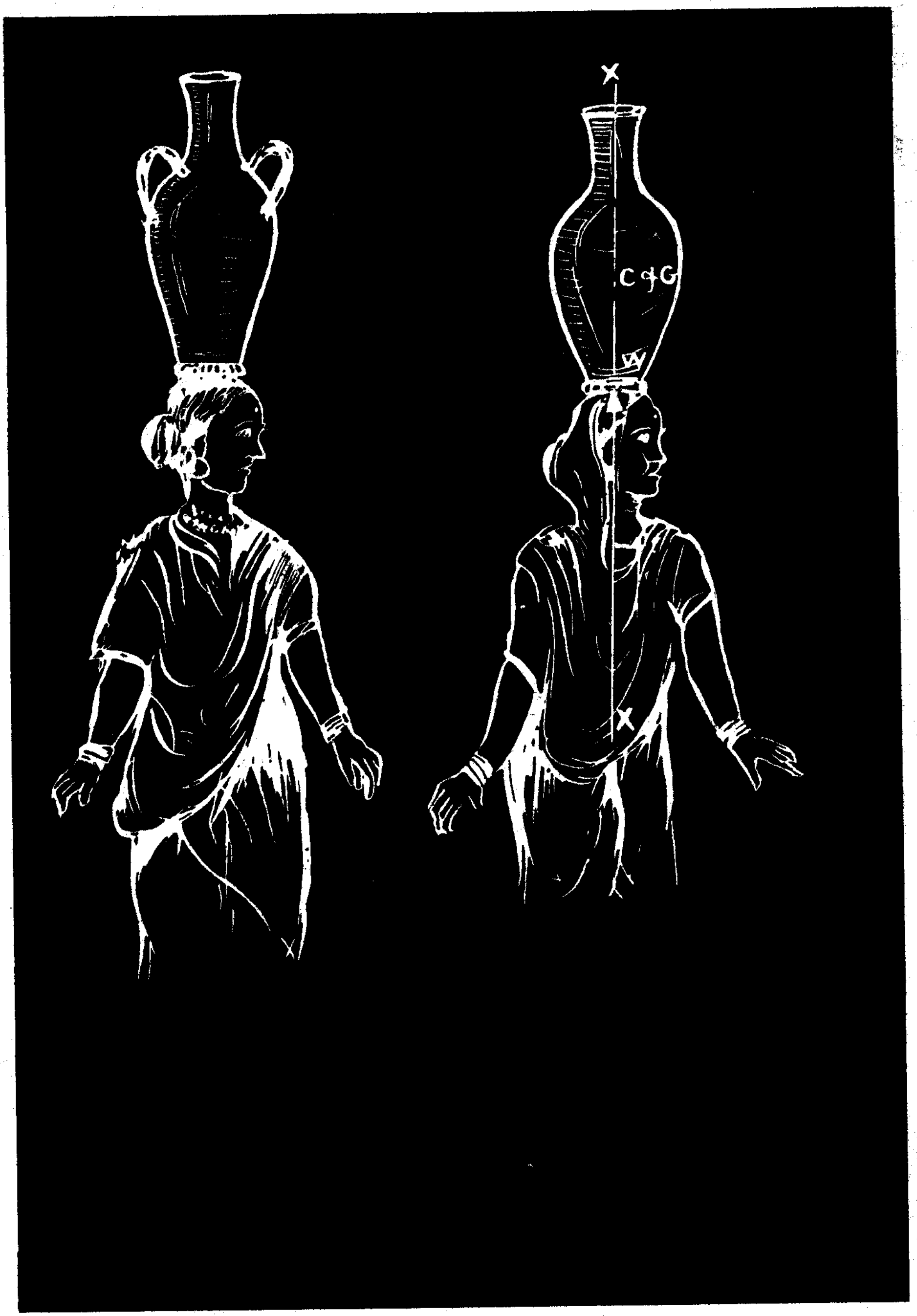

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Fig. 2

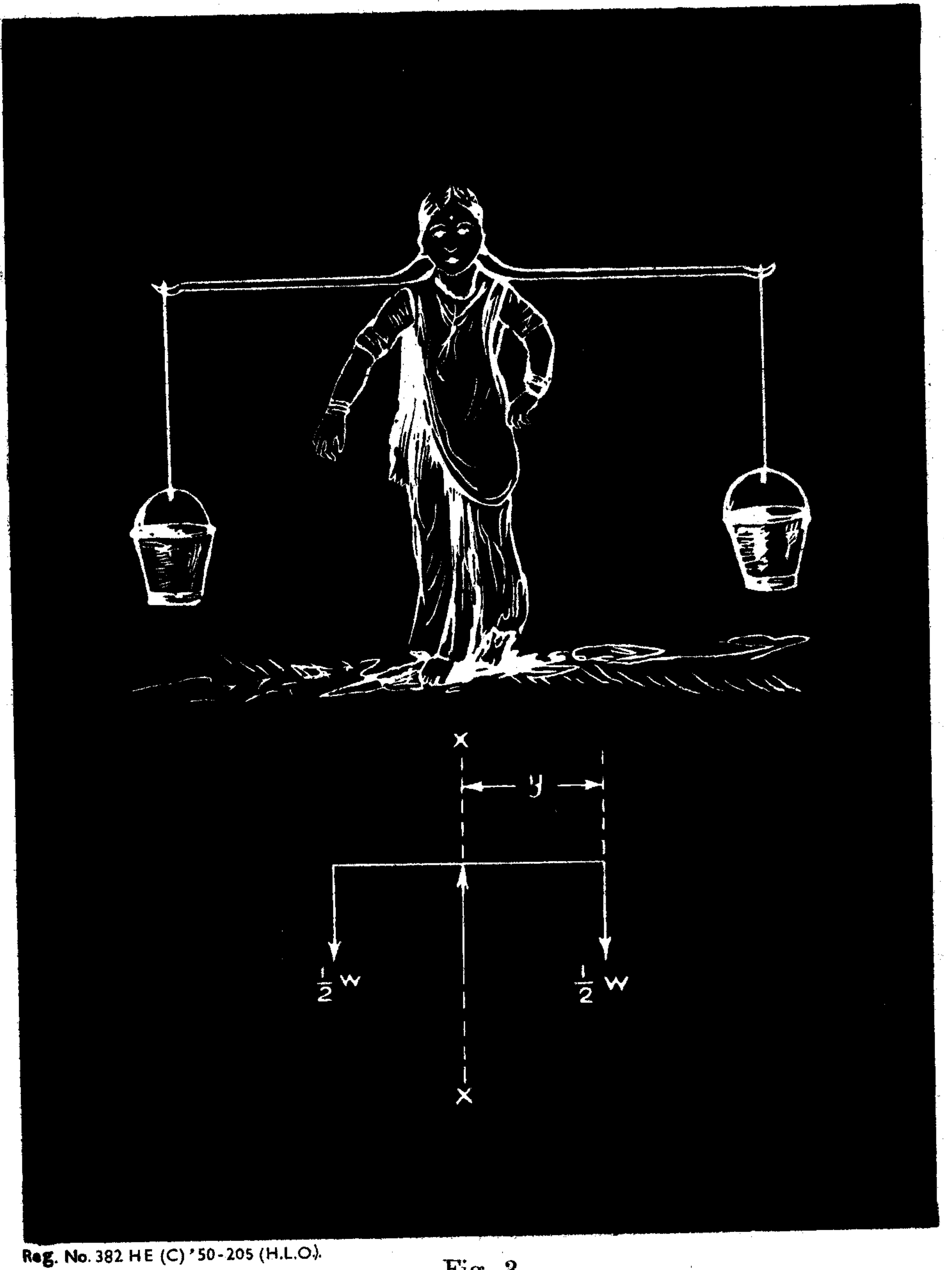

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Fig. 3

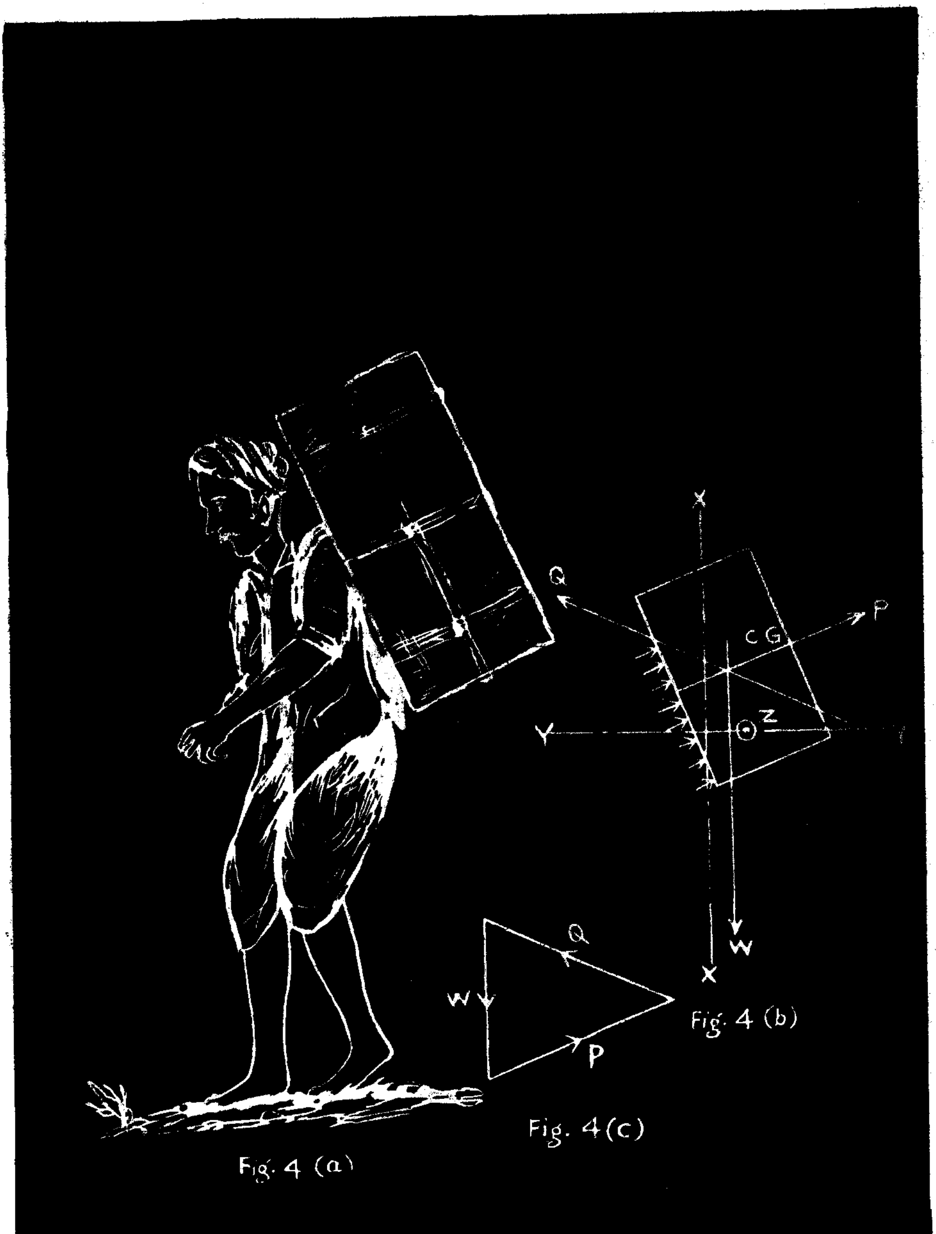

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Fig. 4

Other Factors.—Now, besides the analysis of the various forces acting on the load referred to above, the principles of load-carrying by man involve other factors.

In order that the load may be carried comfortably without fatigue, equilibrium has to be established between the forces acting on the load when the man is moving in different terrains. One of the important factors for obtaining the equilibrium is support of the load.

Man's body, besides other things, is made of bones and muscles. Bones are rigid structures and support weight passively, but muscles when used involve expenditure of energy due to their contraction, etc., and, fatigue, therefore results. The best and the easiest method of carrying load, therefore, will be when maximum advantage is taken of the support given by bones and muscles are used to the minimum thereby a least amount of energy due to muscular action is lost.

An excellent example of this principle is the carriage of load on head. (Fig. 2).

Statically this is a 100 per cent. efficient method. The supporting force exerted by the body is exactly equal to the weight of the load. The hands and the body are free. The posture is erect and the gait is practically normal. The weight of the body is transmitted through the head direct to the vertebral column so that little muscular effort is utilised in direct support. From the kinetic point of view, the centre of gravity coincides with the vertical axis of rotations, turning is, therefore, efficient, but it is very unsatisfactory if the rotation starts along the vertical planes. Therefore, the art of carrying load on the head is quite satisfactory on easy, level grounds, but it becomes impracticable on difficult terrains.

Another example of the same principle is the carriage of load by a "Yoke". Fig. (3).

The weight here rests directly on the spine and shoulders, thus sparing the muscles of the arms. The method is again statically efficient, the lifting force being equal and opposite to the total load. The load is concentrated for (distance "Y") from the axis or rotation XX and is therefore very inefficient from the point of view of turning. It may be noted for contrast that similar loads when carried in the hands, as in the case of a stretcher, the muscles of the hands, arms, and shoulders are soon fatigued.

Another part of the body which can give support to the load is the back. If back alone were to give support, the man will have to bend far down which is not always practicable, as there will be no ease and freedom of movement of the body, and the man will feel very uncomfortable, and thereby get fatigued. For ease and freedom of movement, it is desirable, therefore, to keep the body as erect as possible, but from the point of view of "support", flexion of the trunk improves the distribution of weight. This is achieved by hanging the weight on the back from the shoulder by means of shoulder straps. Fig. 4(a).

When carrying loads by using shoulder straps, muscular tension is concerned with the maintenance of equilibrium as a result of which the pull of the load through the shoulder strap places an abnormal strain on the muscles attached to the outer end of the collar bones. In order to reduce compressing action on the muscles, shoulder straps are made broad and are padded with felt or other resilient material. One has to be careful, however, about the tensions created on the shoulder muscles. In most loads, part of the tension is due to the tendency of the load to roll outwards, away from the shoulders, i.e., turning in vertical plane.

Before discussing the ways and means of reducing the tension effect (tendency of load to roll outwards), static and kinetic principles involved in the method of carrying load at the back may be considered.

Static Principle.—Here the static principle is quite different from that involved when the load is carried on the head. The body actually exerts forces greater than the total load.

As will be seen in fig. 4(b), there are three forces acting. They are the weight (W) acting vertically down, the forward and upward thrust of the shoulder strap (Q), and the thrust of the back (P) acting through the centre of pressure and perpendicular to the back. The directions of these forces being known, a "Force polygon" (Fig. 4(c)) can be drawn and the values of P and Q obtained in terms of W. The static efficiency is $\frac{W}{P+Q}$ and is less than 1.

If the body could be conveniently bent forward so that P was vertical, then P would become equal and opposite to W, and Q would become zero. This would be a position of maximum static efficiency, but it is not practicable because the body would be in such an unnatural position. It is, however, interesting to observe that for very heavy loads this position is more nearly approached. The inference would appear to be that for light loads, normal posture and ease of locomotion take priority over static efficiency, but for heavy loads static efficiency must take first place. Porters in hills bend their backs considerably in order to support very heavy weight.

Kinetic Principle.—In fig. 4(b) the relation of the centre of gravity of the load to the three axes of rotation XX, YY and ZZ is also shown. In ordinary porterage on roads and tracks, rotations about axes YY and ZZ are insignificant and can be neglected. Loads are usually carried considerably higher on the back than that illustrated and this has the effect of bringing the centre of gravity even closer to the XX axis, thus further reducing the radius of gyration about this axis. Now the XX axis passes through the centre of gravity of the body, and the closer the centre of gravity of the load to this axis, the smaller will be the forces P plus Q and, resulting in the increase of the static efficiency as well as of the kinetic efficiency.

The tension of the straps on shoulders therefore can be reduced :—

(a) By bringing the centre of gravity of the load close to the back and vertically at a position corresponding to the level of centre of two shoulder blades ;

(b) By keeping the centre of gravity of the load high. One must not, however, raise the centre of gravity so much so that it goes to the other extreme and creates a torque force tending to throw the man forward on his face ;

(c) By giving a counter-support at the level of the pelvis ;

(d) By using head band as illustrated in Fig. 5. The advantage of this lies in the direct transmission of weight to the skeleton so that muscular effort is required for balance only and not for support. In mountain warfare, however, the head band has the serious disadvantage that it fixes the head and thus restricts the field of vision. Its use in forward areas is therefore confined to porterage on known tracks.

Method of Carriage.

Based on the above principles, a number of Carriers have been designed. The design of the carrier has to be such that a reasonable degree of mechanical efficiency is achieved without unduly upsetting freedom of the shoulders and hips, natural erect position, and normal gait. Great attention has, therefore, to be paid to the distribution of pressure and reduction of load on muscles. Some of the different types of Carriers introduced for Army use are described below :—

Haversack of the Web Equipment.

Principle.—The weight is hung on to the back by means of shoulder straps. The entire support is provided by the shoulder muscles thus enabling the wearer to maintain his body in the upright posture and to have complete freedom of movement.

Advantages.

1. Can be easily slung on to the shoulders.
2. Correct posture of the body is maintained while walking about with the haversack in position.
3. Ensures freedom of movement and speed.

Disadvantages.

1. For loads greater than 20 lbs., it becomes uncomfortable to wear on account of strain produced by shoulder straps which provide the only means of support.
2. The load is borne by the muscles which get easily fatigued with greater loads.
3. Tendency for the loads to roll out—reduces the kinetic efficiency as :—

   (a) radius of gyration increases, and

   (b) the centre of gravity falls away from the spine.

Manpack Carrier.

Principle of the carriage has already been discussed in previous paragraphs (Fig. 4).

The following are the various types of Carriers Manpack in use :—

(a) *Carrier, Manpack, G.S.* (*U.K. Pattern*). (Illustrated in Fig. 6).—This is a light alloy metal frame, which is slung in position by means of shoulder straps. The points of application of load are the shoulders and the back. In addition, head band is also provided which when brought into use is intended to take off the load from the shoulders and shift it to the skeleton. This is to provide relief for the shoulder muscles which would otherwise get fatigued. The load can be raised and the centre of gravity moved forward and higher thus increasing both static and kinetic efficiency.

Advantages.

1. Uniform distribution of the load on the back.
2. The head band provided for occasional use could be very beneficial. But in the existing design it cannot lift the load off the shoulders. The advantage which was intended to accrue is thus lost.

Disadvantages.

1. The ventilation of the back is not proper.
2. The depth of the frame is low and causes discomfort to men of smaller stature, i.e. 5′ 6″ and below.
3. The method of attachment of load is not satisfactory. The straps provided are not suitable for securing awkward loads.
4. The head band as explained above is not properly positioned.

(b) *Packboard, Metal* (*Indian Pattern*). (Illustrated in Fig. 7). This is manufactured from light alloy metal tubings and has the following additional features as compared to item (a) above :—

1. The shoulder straps can be so attached that the entire Packboard is raised or lowered—raised for heavier loads and lowered for lighter loads.
2. The depth is sufficient to ensure equal comfort to men of various stature.
3. Thump loops have been provided for hitching up and easing the load occasionally.
4. There is better ventilation of the back.
5. Shoulder straps and head band are all padded with felt and are therefore more comfortable to wear.

(c) *Packboard, Plywood* (*modified Indian Pattern*).—This is a plywood press-out job with a stretched canvas back rest and incorporates all the desirable features of the Carriers (a) and (b) above.

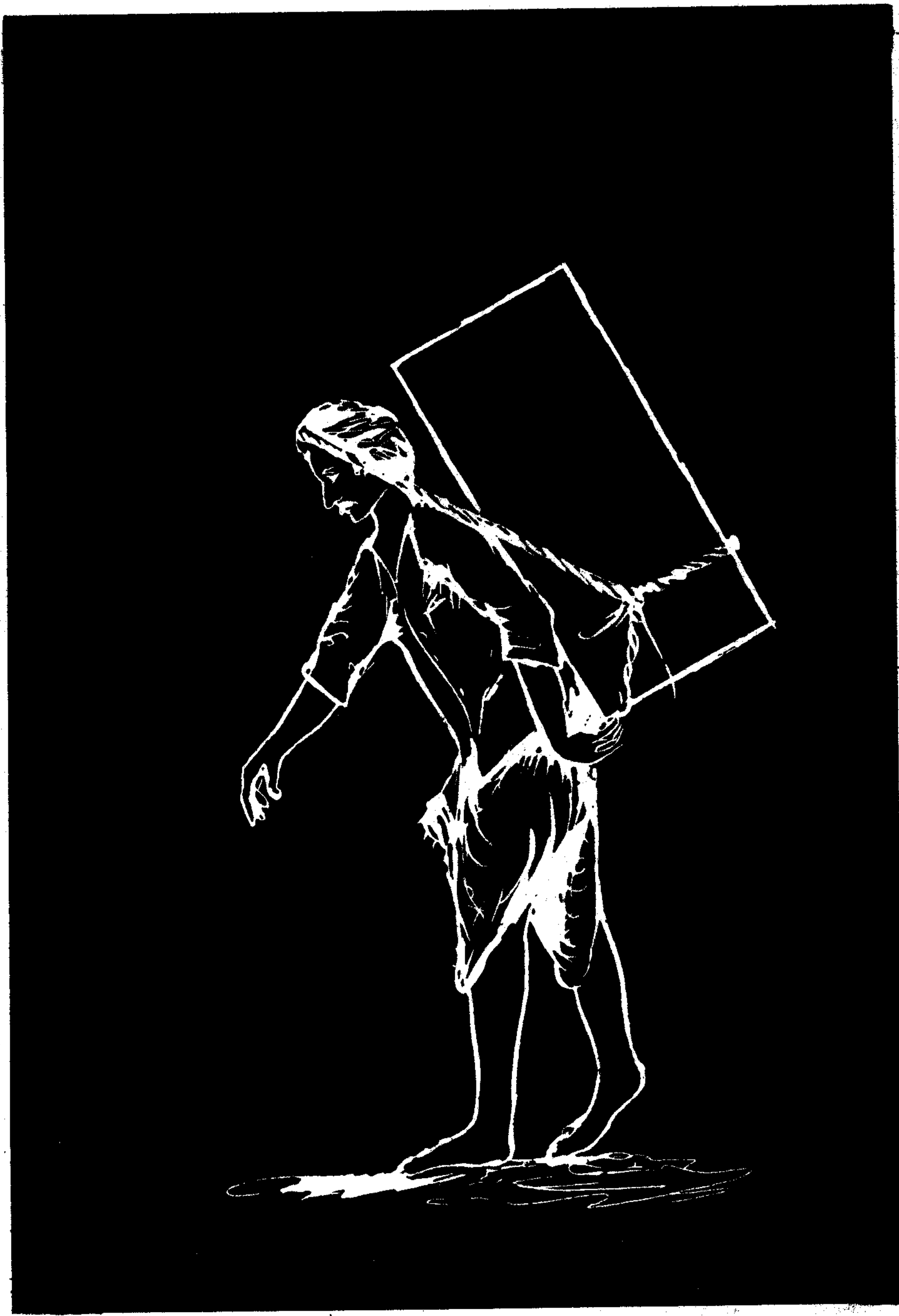

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Fig. 5

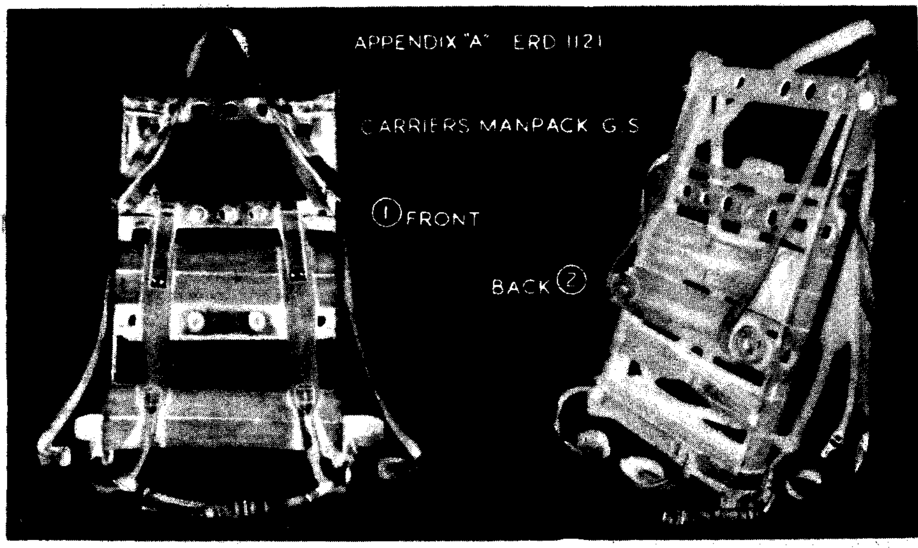

Fig. 6

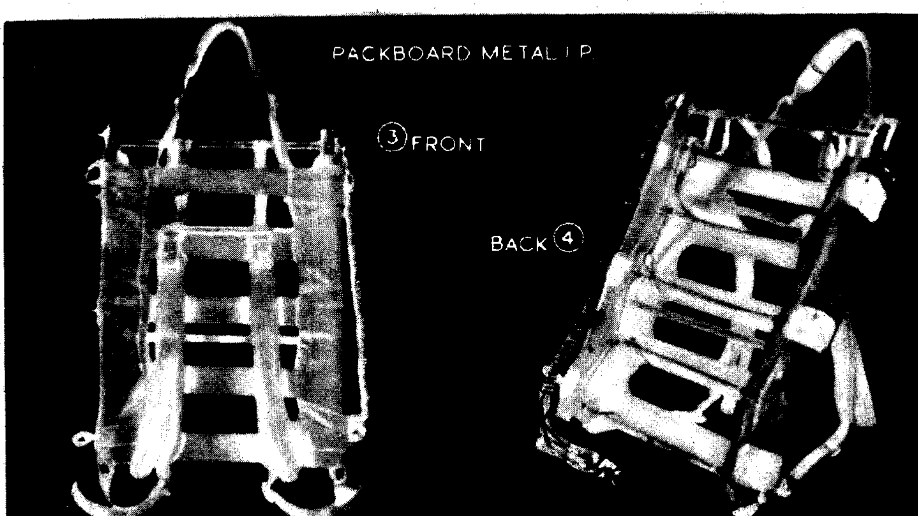

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Fig. 7

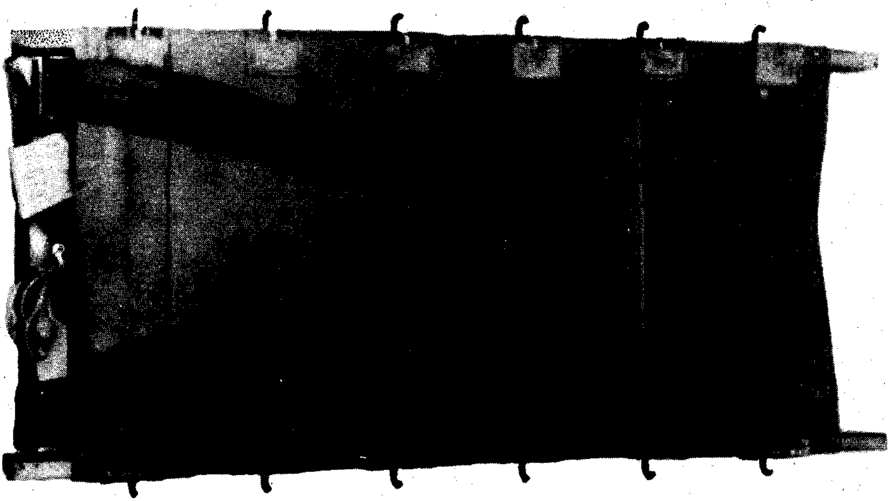

Fig. 8

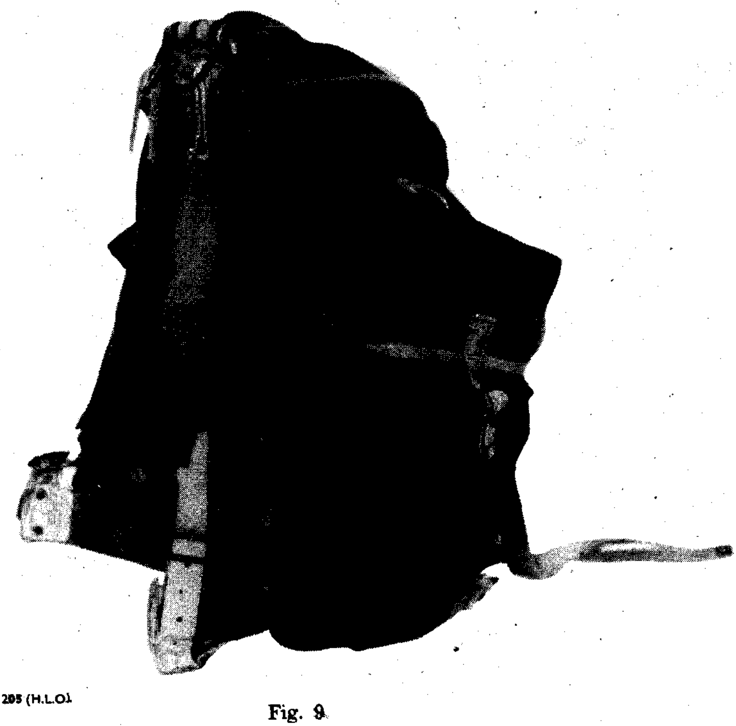

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Fig. 9

In addition, the load rests inclined at an angle to the vertical in the normal position itself so that the centre of gravity when raised is brought forward and thus the load is borne more by the spine, thus reducing muscular fatigue.

(d) *Pack, Yukon.* (Fig 8, without Platform).—This is a sturdy frame made from timber and is provided with a platform for the load to rest. The carriers at (a), (b) and (c) above are light structures suitable for loads upto 50 lbs.

The Pack Yukon, however, is essentially designed to carry heavy loads which can be raised to the maximum effective limit of height. But this entails increased flexion of the trunk and thus hampers freedom of movement.

Advantages.

1. The pressure is uniformly distributed over the back.
2. The load can be raised to bring the centre of gravity nearer to the body and the vertical axis of rotation. Better static and Kinetic efficiency is thereby achieved.
3. The posture of the body, consequent on (2) above, can be maintained more erect ; this, however, entails more muscular effort since the load is chiefly supported by the shoulders. The effect, can be neutralised by the increased bending of the spine which will result in moving the centre of gravity forward thus relieving the shoulder muscles. This posture is however uncomfortable for working.

Disadvantages.

1. The back is not properly ventilated because the entire board is in close contact with it.
2. For lighter loads it does not afford any special advantage, as much of the muscular energy will be spent to support the load in this type as in any other. It is rather a heavy and clumsy piece of equipment for light loads.

Rucksack Bergen with frame. (Fig. 9).

Principle involved in Rucksack Bergen with frame essentially differs from that of the Carrier, Manpack in that the load is not distributed over the back. It is concentrated on the waist-band which provides the only point of support. This ensures complete freedom of movement to the shoulders and the body, but at the cost of mechanical efficiency, since the centre of gravity of the load cannot be either raised or moved forward. The weight is far from the vertical axis and the body, thereby reduces both the kinetic and the static efficiency.

Advantages.

1. It has a capacious bag for articles which can be packed separately in separate pockets.
2. The main support is provided by the waist-band which fits over the hip thus relieving the strain on the shoulders and keeping them free to move.

3. The entire back is free from any contact with the load. This provides ventilation. It is particularly useful in tropical climates.

Disadvantages.

1. The area supporting the weight being considerably small, i.e., the waist-band—increased load becomes rather uncomfortable and tiring. Over 50 lbs. the intensity of pressure becomes unbearable.
2. There are no means to bring the centre of gravity of the load nearer to the vertical axis either by means of raising the load or by altering the method of packing. This results in both static and kinetic inefficiency.

Carrier, Everest. (Fig. 10).

Principle involved in Carrier Everest is the same as that of the Rucksack, Bergen, but the points of application in this instance are on the shoulders and on a point under the waist-band which can be varied by alteration to the length of straps. This type of carrier, however, permits the change of centre of gravity by suitable packing without alteration to the points of application of the load.

From Fig. 11 it will be seen if moments are taken about point A on the shoulder then :—

$$P \times h = W \times d \text{ or } P = W \times \frac{d}{h}$$

If h is increased, it is true that d will also increase slightly due to the posture of the body. It is not possible to state exactly how much it will increase, because the shape of the back is not a straight line. It can be said, however, that this increase is very small compared with increases in h.

Hence P is approximately equal to constant h.

Hence if h is increased, P will be reduced.

It is therefore an advantage mechanically to have the waist-band low.

From anatomical considerations, however, there are certain limitations with regard to the point of application of load. For instance, should it be very low it would impede the working of the legs. From this view point the best point is sacrum. The lumber region (small of the back) is worse, because of the direct pressure on the muscles. It is bad from mechanical considerations as will since the point of application is high. A mistake is also often made to raise the load (centre of gravity) by tightening the shoulder straps instead of repacking the load correctly and adjusting centre of gravity. Therefore one has to pack the load correctly and adjust the Carrier so that working of the legs is not impeded.

Advantages.

1. The Everest Carrier does not rest on the entire back, which is good in tropical climates for the purpose of ventilation of the back.

2. Unlike the Rucksacks the load in this type of carrier can be suitably packed to raise the centre of gravity, thus bringing it forward and nearer to the vertical axis of rotation. Better kinetic efficiency is thus achieved.

Disadvantages.

1. The load being concentrated on the waist-band the intensity of pressure becomes unbearable with loads beyond 50 lbs.

2. The load cannot be moved far enough to bring the centre of gravity very close to the vertical axis. For heavier loads with the centre of gravity away from the spine both static and kinetic inefficiency result.

Loading.

From the above it will be clear that in order to carry the load comfortably besides the selection of proper carrier, the loading/packing of different weights has also to be done carefully, e.g.—

(a) The heavier components of a load are packed close to the body to bring the centre of gravity of the load forward, thus increasing static efficiency and ease in turning in the horizontal plane.

(b) Heavy objects are packed high in order that they may be brought farther forward.

(c) Flat loads are packed closer to the back.

(d) Long objects are packed with their least radius of gyration perpendicular to the vertical axis of rotation, because this is the axis about which most movement takes place.

(e) Bulky loads cannot be carried so efficiently because more energy is required to carry them than less bulky loads of the same weight.

It will be obvious after considering various type of carriers that although number of carriers have been designed, yet there is no universal carrier which can be used to carry loads both light and heavy comfortably and it is in this direction that further research work is suggested.