A.M.E.

MILITARY TECHNICAL COLLEGE

CAIRO - EGYPT

WALKING VEHICLES +

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ABSTRACT

Off-road mobility plays a key role in several development activities such as agriculture, construction, land reclamation, mining and petroleum. Despite the fact that national development in Egypt is directed towards the exploitation of the desert , no serious attention has been given to promote research work in problems of land mobility in desert areas. This paper seeks to initiate interest in research and development in off-road mobility especially on sand. It outlines some of the concepts of land mobility in nature and describes some man-made vehicles utilizing the walking concept to negotiate soft loose terrain.

INTRODUCTION

The wheel is the basic means of mobility for man-made land vehicles, whether it runs on-track or on-road. It is the most simple and efficient mechanism for mobility on paved roads. If a wheel is rigid and moving on a rigid surface such as in railroads, the rolling resistance could be as low as 2.5 Kp/ ton load. When moving off-road, particularly on soft loose soil, the wheel is much less efficient; the resistance to motion could reach as high as 150 Kp/ton load (1) . As a result of the low shear strength of such soil, a driving wheel tends to mill and sink deeply in the soil impeding traction.

+ Invited key-note lecture.

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In order to improve off-road performance, the wheel is made to run on a track laid by the vehicle. The price of a tracked vehicle is considerably higher than a corresponding wheeled vehicle. In military applications the initial cost is possibly as much as double. With the frequency of major repair being nearly five times that of a wheeled vehicle, the life cost ratio would be 10 to 1 against the tracked vehicle (2) . The order of cost ratio becomes higher if considering the track capabilities are probably utilized only 10% of the life time (2); the rest of the time the vehicle runs on road, either selfpropelled or carried on another wheeled vehicle.

A significant amount of research and experimental work has been devoted to solve the problems of off-road mobility(3) . One of the attracive approaches is to adapt the efficient means of mobility in nature,namely walking, to man-made vehicles.

MOBILITY IN NATURE

Bekker (1) has surveyed the mechanics of important types of mobility in nature, namely flow in a channel, leaping, running, crawling, sliding, and walking. He developed expressions for the power required per unit weight for each mode of mobility. This power is lost during motion.

For water flow in a channel the required power P per unit weight of water W may be expressed by the relation

$$\frac{P}{W} = k\, v^3$$

Where v is the velocity of water flow
k is an empirical factor depending on the characteristics of the channel wall and its cross section
This relation is plotted in Fig. 1.

Leaping is a type of motion in which the body starts from standstill on the ground, then it takes off the ground with its center of gravity describing a parabola then landing again lo sing its total kinetic energy. The required power per unit weightof a leaping body may be expressed by the relation

$$\frac{P}{W} = \frac{v_o}{4 \sin\alpha}$$

Where v_o is the initial velocity imparted by the muscles
α = inclination of the initial velocity to the horizontal

Running is essentially a series of consecutive leaping. In this case, however, only the vertical component of v_o is lost while the horizontal component is maintained nearly uniform. Thus,running consumes less power than leaping.

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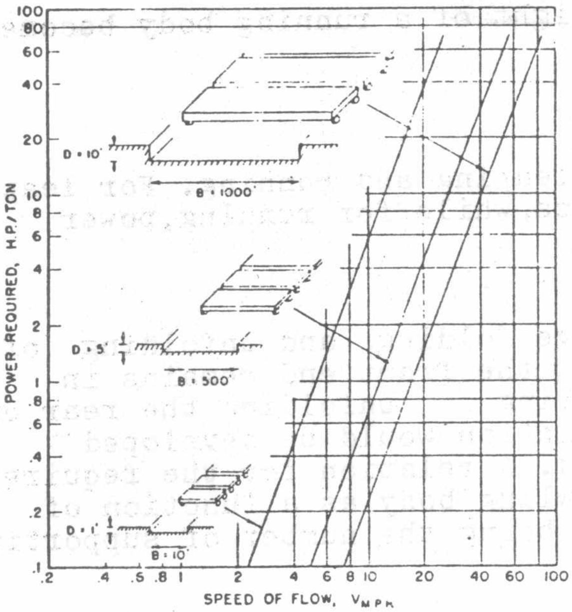

Fig.1-Flow in a channel
(After Bekker)

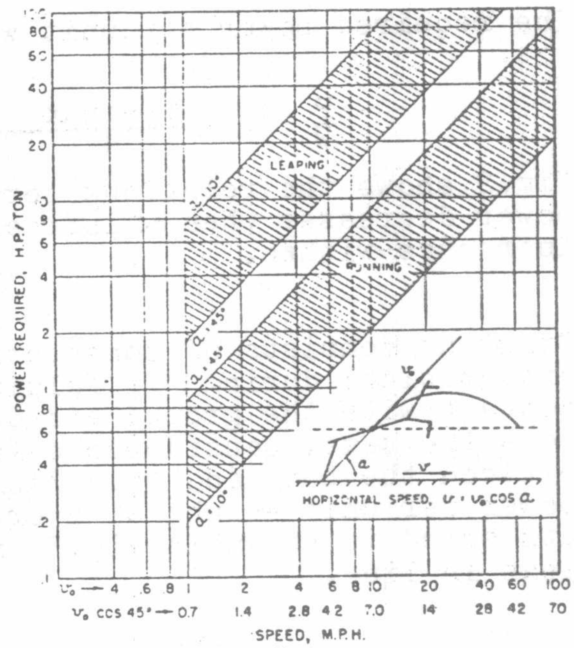

Fig.2-Leaping & Running
(After Bekker)

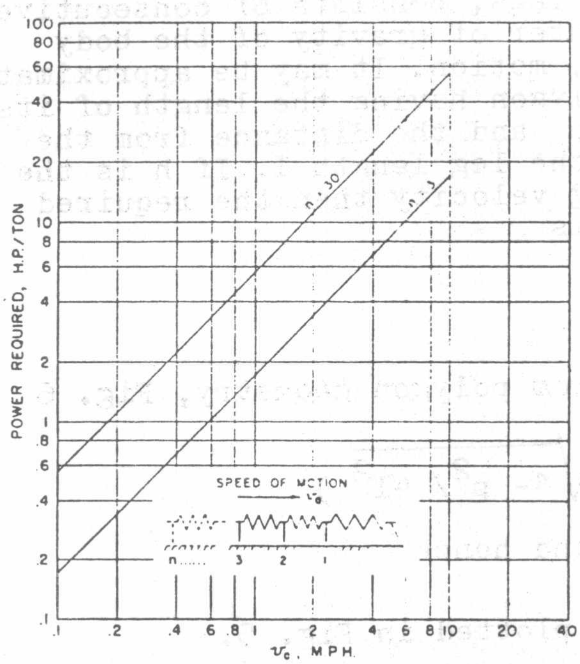

Fig.3- Crawling
(After Bekker)

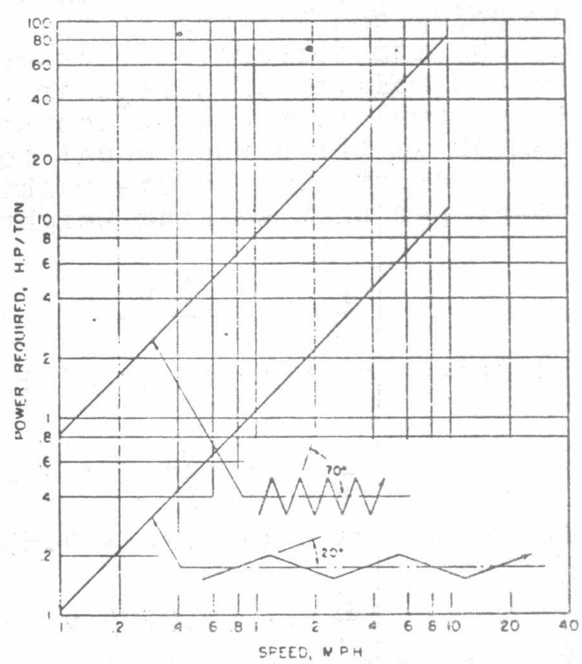

Fig.4- Sliding
(After Bekker)

The required power per unit weight of a running body becomes

$$\frac{P}{W} = \frac{v_o \sin \alpha}{4}$$

Fig.2 shows the relations for leaping and running. For leaping, power decreases when α increases, while for running, power increases with α.

Crawling consists of consecutive folding and unfolding of extremities; during folding the front end remains in contact with the ground and during unfolding the rear end does the same. Considerable friction would be developed between the body and the ground. A relation for the required power per unit weight of a crawling body as a function of its speed is shown in Fig.3; n being the number of supporting legs in line.

In sliding, longitudinal movement is performed in such a way that the whole body follows a zig-zag path on the ground which corresponds to the snake motion. The relation for the power per unit weight of a sliding body as a function of its forward speed is shown in Fig. 4.

Walking of a biped, i.e on two legs, consists of consecutive dropping and lifting of the center of gravity of the body during its forward, or backward, motion. It may be approximated to the rolling of a regular polygon having the length of its side equal to the step length p and the distance from the center to the corner equal to the leg length l. If h is the lift per step, v is the walking velocity then the required power per unit walking weight is

$$\frac{P}{W} = \frac{v\ h}{p}$$

Substituting h in terms of l from polygon geometry, Fig. 6

$$\frac{P}{W} = \frac{vl}{p} \left(1 - \sqrt{1 - p^2/4l^2} \right)$$

For an average man l/p = 1.65 and hence

$$\frac{P}{W} = 0.0775\ v \qquad \text{plotted in Fig. 5.}$$

Referring to Fig.6 it is obvious that the smaller the step, the more sides to the polygon and the closer it approaches a circle. Thus, rolling of a wheel is a limiting case of walking . This constitutes the logical basis for adapting walking to off-road vehicles.

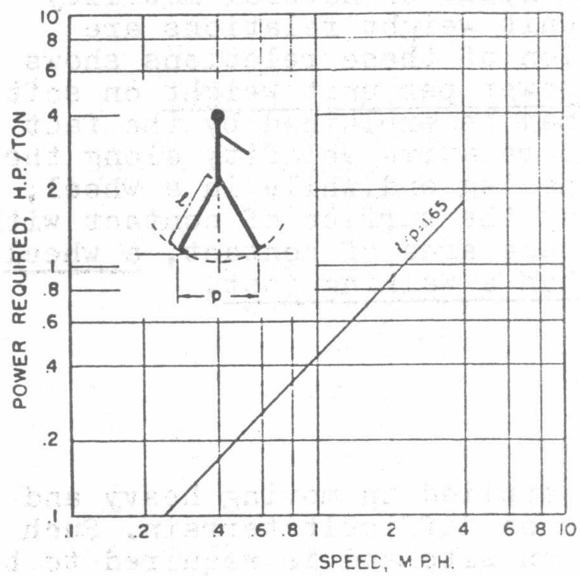

Fig.5- Walking
(After Bekker)

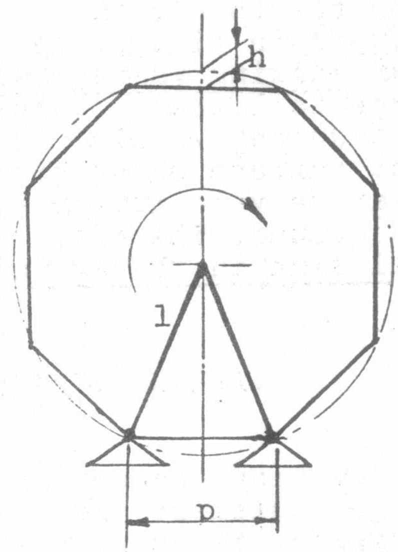

Fig.6 Rolling Polygon

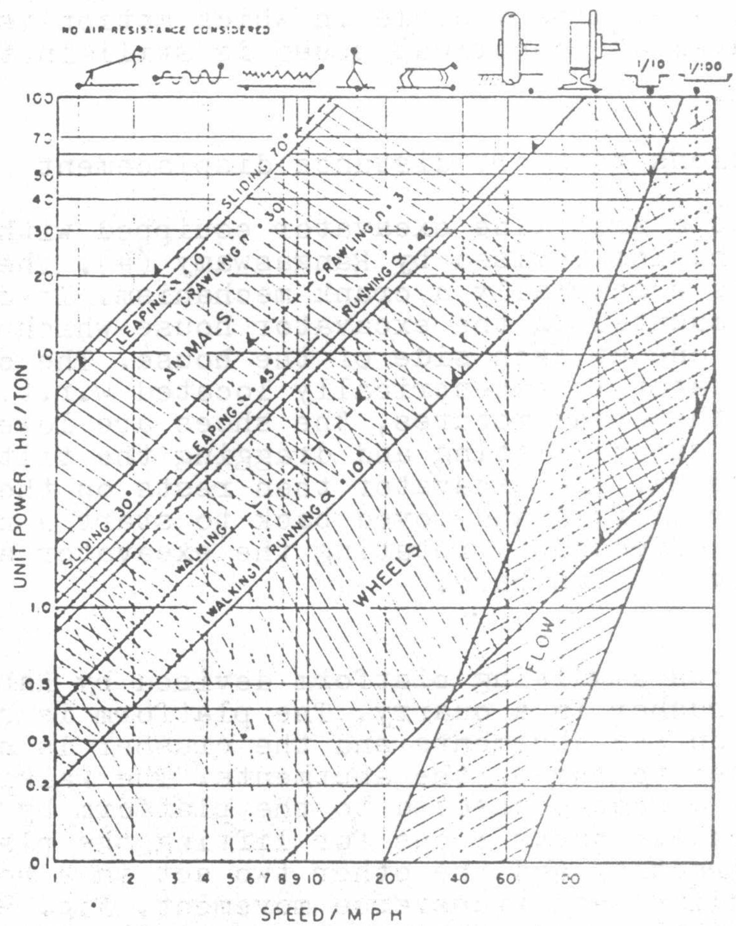

Fig.7-Comparison between various modes of mobility (After Bekker)

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In order to compare the various modes of natural mobility with the wheel, the power per unit weight relations are grouped in Fig. 7. An examination of these relations shows that walking wastes much less power per unit weight on soft loose soil than a wheel. This may be explained by the fact that during walking there is no relative velocity along the foot surface being hinged to the leg end, while in a wheel, relative velocity prevails along the surface of contact with the ground. Therefore for the same area of contact, a wheel will sink in the ground more than a walking foot.

WALKING VEHICLES

The walking concept is already applied in moving heavy and large equipment short distances on difficult terrain. Such equipment is usually assembled on site and is required to be relocated after assembly. The site conditions together with the weight and size of the equipment would make movement by other means such as towing or on wheels or track impractical. Typical examples of such equipment are excavators, crushers, boring rigs, rigs for driving piles and cranes in construction sites. In these applications the motion is intermittent. On the other hand, a walking vehicle in which motion is continuous and can travel at economical speed is still in the development stage.

a- Applications to short distance displacement

Fig. 8 shows a drag line excavator equipped with an improved walking mechanism devised by Rangaswamy (4). The walking mechanism is essentially a crank mechanism. It comprises a crankshaft mounted in the excavator house which drives two long shoes; one at each side of the house. The center of gravity of the excavator is eccentrically located w.r.t. the crankshaft center. As the crank rotates, the shoes are lowered and press against the ground lifting and dragging the tilted excavator over the ground. The excavator then rests on the ground and the shoes are lifted and moved back to start a new cycle. Steering is effected by rotating the excavator about a vertical axis relative to its base.

Fig. 9-a shows a walking platform devised by Rabinovitch (5) to move a crusher in a quarry. The platform is supported on the ground on two abutments and the crusher is eccentrically placed closer to one of the abutments. The walking mechanism consists of a shoe connected to the platform by three double-acting hydraulic jacks ; one for lifting the platform in the vertical direction and the other two act in a horizontal plane for longitudinal and transverse movement. Fig. 9-b shows the operation of the system. The cycle consists of first lifting the platform, getting it dragged in the direction A, then lowering again to the ground. Steering is effected through the transverse jack.

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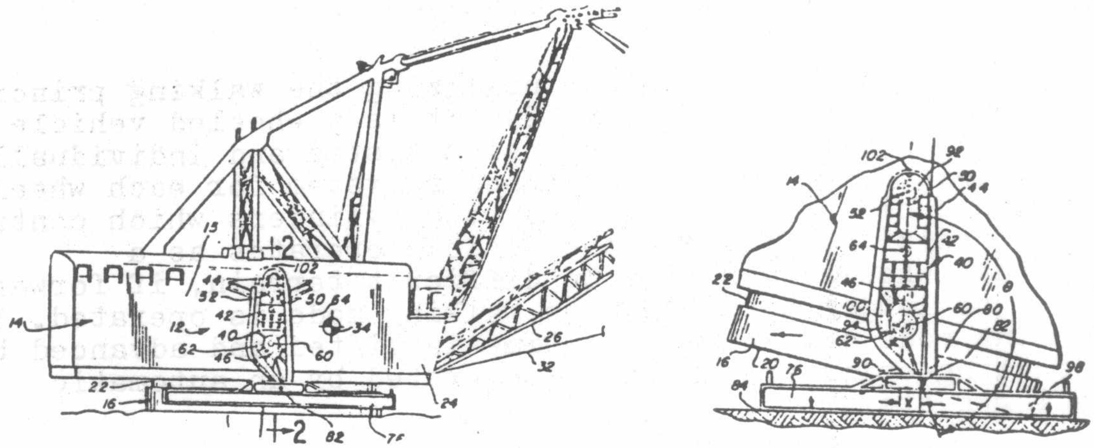


Fig.8 Drag line excavator equipped with an improved walking mechanism (After Rangaswamy)

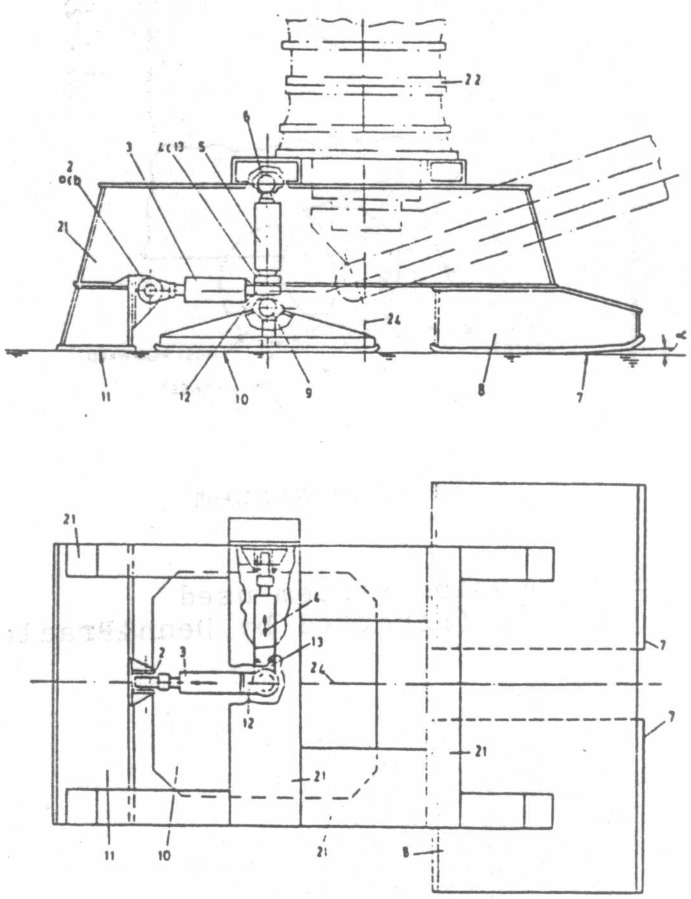


Fig. 9-a Walking platform (After Rabinovitch)

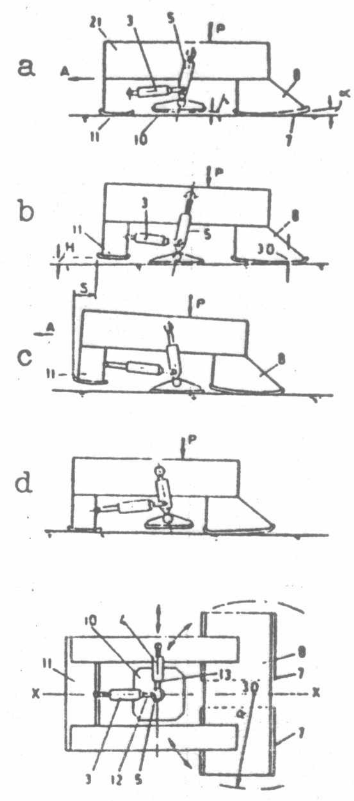
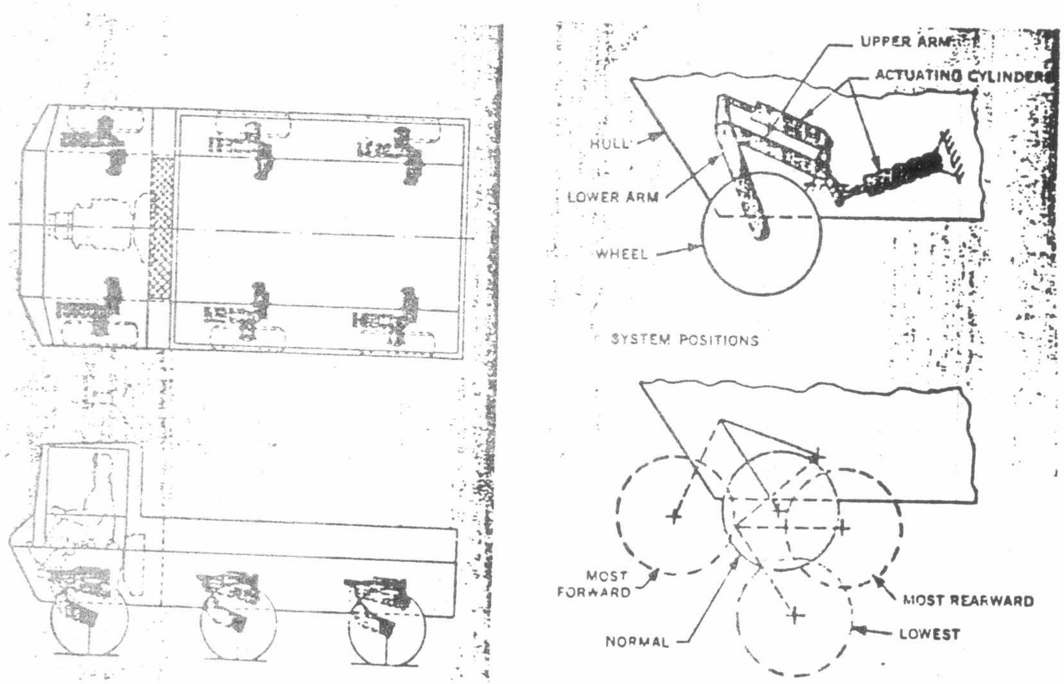


Fig.9-b Platform walking cycle (After Rabinovitch)

b- Applications to vehicles

A concept for a military vehicle utilizing the walking principle is reported by Denn and Bradley (2). It is a wheeled vehicle with controlled articulated suspension system and individually powered wheels, Fig. 10. The suspension system for each wheel is a knee and hip joint actuated by two cylinders which control the wheel position. Normally the vehicle operates as a conventional wheeled vehicle. On difficult terrain, if forward motion is no longer possible, the walking mode is operated. In the walking mode,one wheel at a time is lifted and advanced by the actuating cylinders which are operated by an automatic sequencing system.



Wheels layout

Walking system

Fig.10 An articulated suspension system used for emergency walking (Reported by Denn&Bradley)

6 A " walking wheel " devised by the author (6) is indicated in Fig. 11-a,b,c&d. It has the same properties of an ordinary wheel namely : its center remains at a constant height form the ground, it travels at a speed linearly related to the driving shaft speed and its motion is continuous. The advantage of this wheel over an ordinary wheel is that the load is supported on a large surface of contact with no relative velocity. This will reduce sinking and eliminate milling during traction on soft loose ground.

The walking action is obtained by substituting the ordinary large wheel by three lobe-shaped smaller planetary wheels which support load successively, Fig. 11-a. The lobed wheel supporting load remains stationary in contact with the ground while the vehicle axle travels uniformly at a constant height. Contact starts and ends smoothly with no relative velocity and there is adequate overlap to maintain continuous motion. If the center distance between two wheels is p and the driving shaft rotates at N rpm then the vehicle speed v is

$$v = p N$$

In one of its possible designs, the walking wheel is shown in Fig. 11-b and Fig. 11-c. It consists of three lobe-shaped inflated wheels 1 in mesh together; each wheel is free to rotate on axle 2 and are symmetrically mounted in a cage 3 . Cage 3 rotates on a crankpin 4 and is connected from each end to a flange 5 which carries three roller followers 6 moving on a profiled cam surface 7 . The profiled cam surface is rigidly fixed on each end to the wheel bearing support 8 and sealed by a disc 9 . Two rotors 10 are mounted on the crankshaft, one at each end, to provide dynamic balancing and are used for driving and braking. The entire assembly is clamped to the vehicle chassis at supports 8 .

Several arrangements of the walking wheel are shown in Fig. 11-d, depending on its application. A single wheel could be utilized as a temporary device in an ordinary wheeled vehicle to assist in negotiating difficult terrain. The four-wheels in-line arrangement could be the basis of a specially designed desert vehicle.

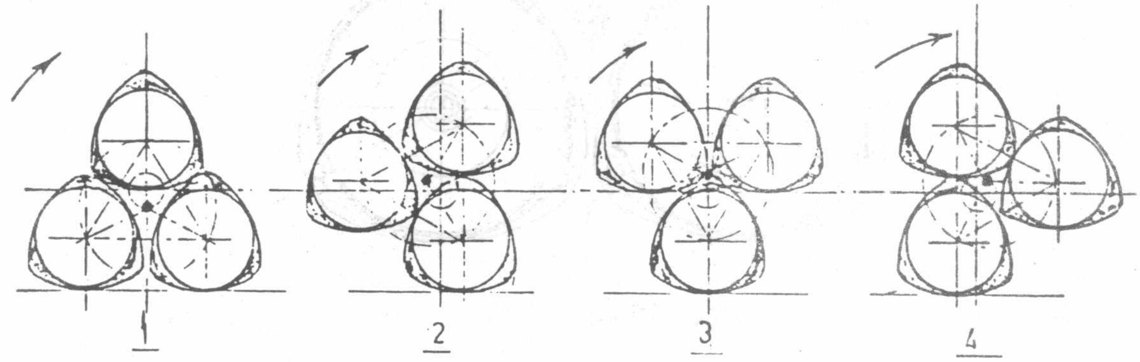


Fig.11-a Successive wheel configurations

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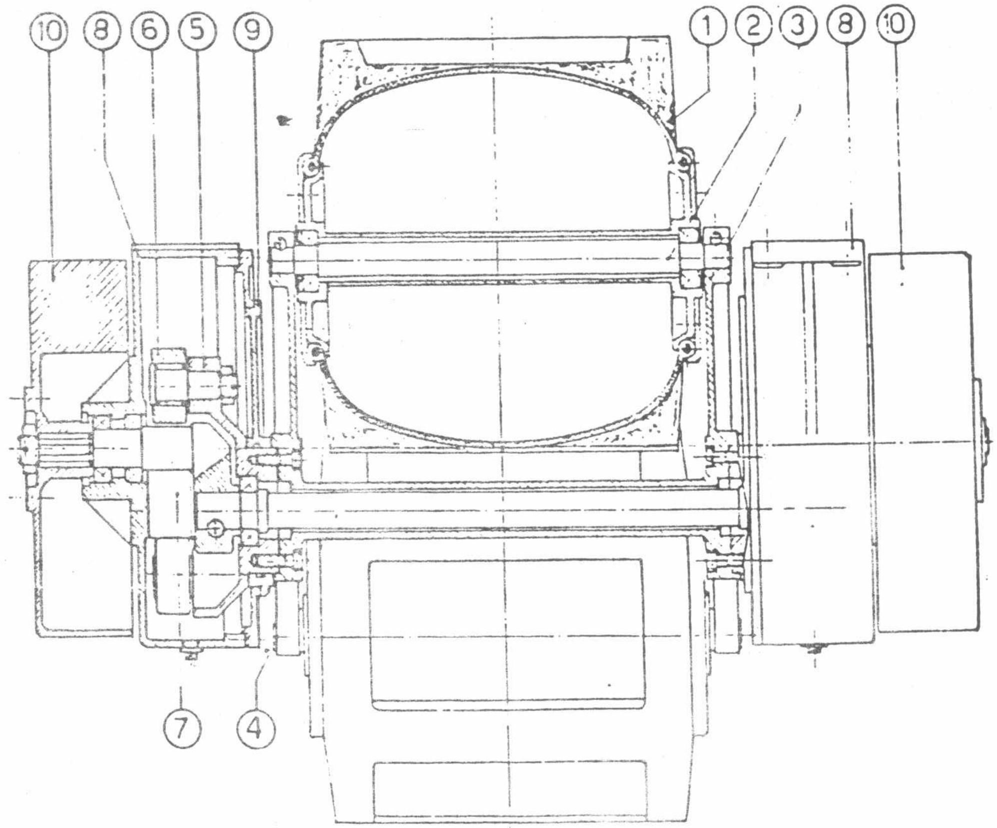

Fig.11-b

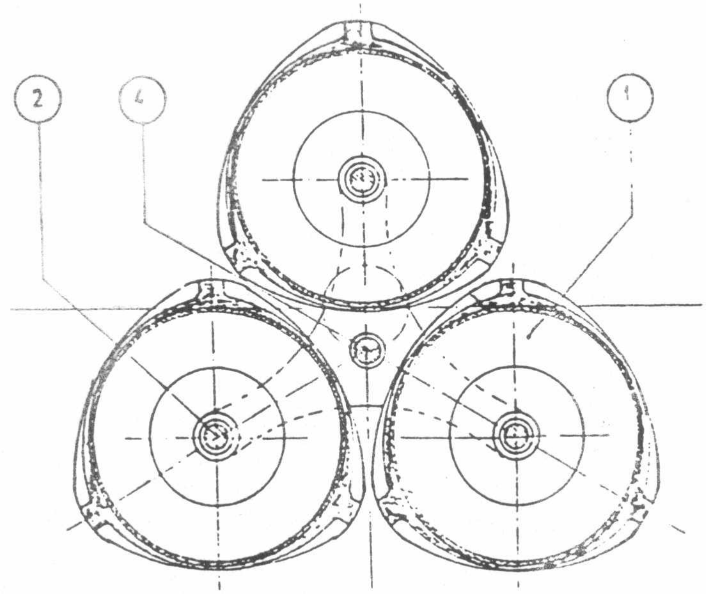

Fig. 11-c

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Fig.11-d Arrangements for the Walking Wheel

RESUME'

The wheel is an efficient means of mobility on paved road or track. Off the road, the wheel is no more efficient and tends to fail in traction on soft loose ground. At the high life-cost of a tracked vehicle, a walking vehicle is more economical and could be an attractive proposition for off-road mobility. In order to promote national plans for desert exploitation, it is necessary to sponsor research and development in mobility in desert areas along with other current desert research work.

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(4) Rangaswamy K.,"Offset Walking Spud" U.S. Patent 4334587 June 15, 1982.

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