LOOPWHEEL* SUSPENSION SYSTEM DEVELOPMENT STATUS

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ABSTRACT

The LOOPWHEEL suspension concept as developed at **LOCKHEED's** Res. & Engrg. Center in Huntsville, AL., USA, represents a new approach to off-road mobility taking advantage of modern high strength composites. A normally cylindrical and barrel-shaped filament-wound composite ring properly installed in a vehicle can combine the functions of load distribution over a large foot print as well as spring suspension in a simple one-piece structure.

Results from early field tests of a 1.4-ton test vehicle built under US-Army TACOM contracts are discussed. The LOOPWHEEL's excellent ride qualities were overshadowed by their very poor durability and high rolling resistence. Refinements in the manufacturing process and in material selection have since led to life times of 22 000 to 32 000 km for 1 m diameter LOOPWHEELS and to acceptable rolling resistance in laboratory tests.

New design options are presented which promise further improvements in durability, on-road and off-road mobility, noise and vibration suppression, lower part count and lower cost for a wide range of attractive applications ranging from low-speed agricultural trailers to high mobility on/off-road motor vehicles.

1. THE LOOPWHEEL CONCEPT

1.1 High Mobility LOOPWHEEL Suspension

The basic LOOPWHEEL consists of one or several circular bands of high-strength filamentary composites with a slight transverse barrel-type curvature, Fig. 1. The concept draws from earlier efforts by **J.G.A. Kitchen** in England and **G. Bonmartini** in Italy who lacked the benefits of modern high strength composites and did not make use of the inherent spring travel of such endless tracks. Initially LOCKHEED's development was aimed at future Moon and Mars rovers, Ref. 1. To this day NASA is rating LOOPWHEEL suspensions among the primary mobility options for Mars rovers, Ref. 2.

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Fig. 1. BASIC LOOPWHEEL STRUCTURE

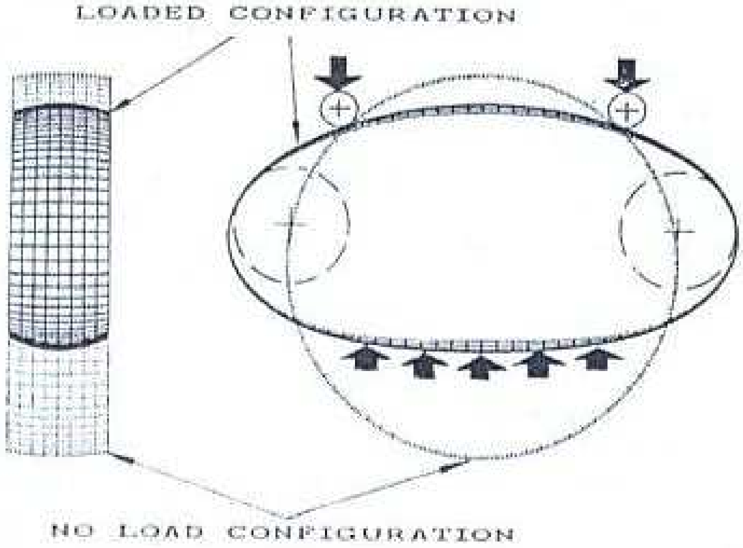


FIG. 2.

HIGH-MOBILITY SUSPENSION

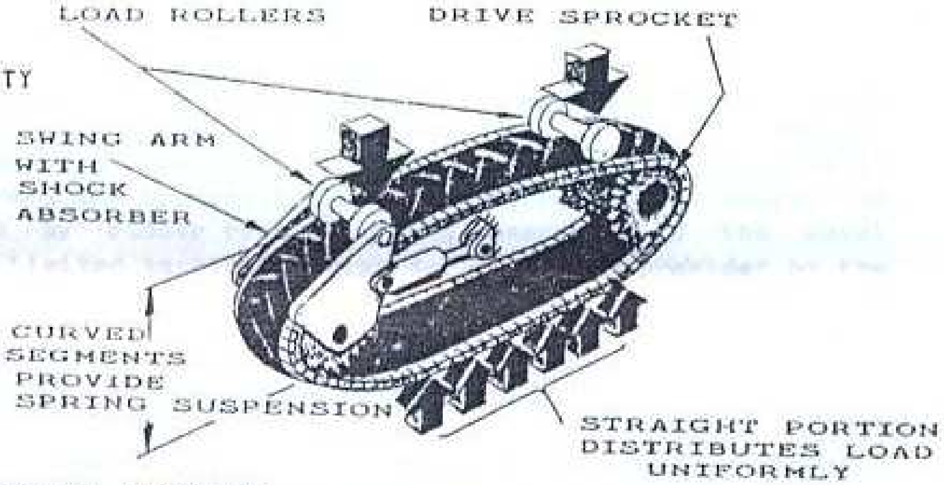
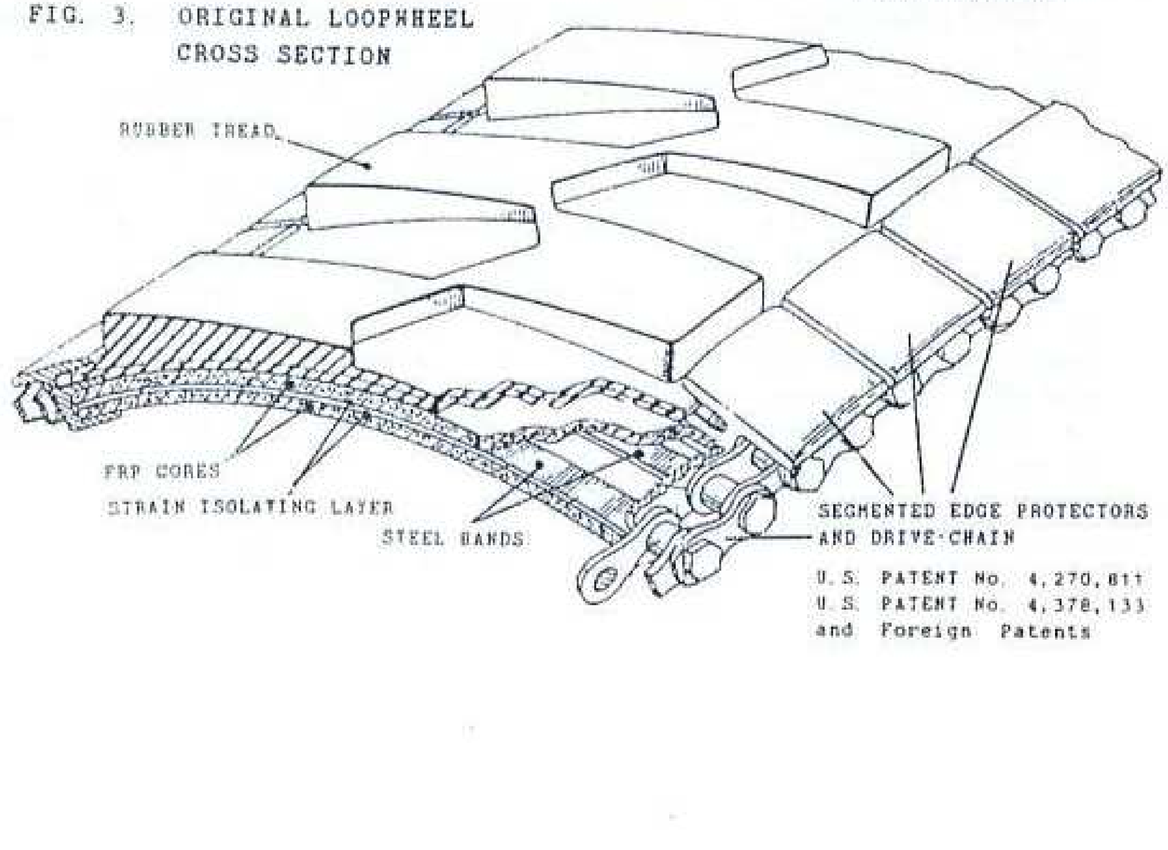


FIG. 3. ORIGINAL LOOPWHEEL CROSS SECTION



U.S. PATENT No. 4,270,811
U.S. PATENT No. 4,378,133
and Foreign Patents

When a vertical load is applied through upper load rollers as illustrated in Fig. 1, the LOOPWHEEL assumes a near-elliptical shape, distributing the load over a large ground contact area. If properly suspended and guided, the LOOPWHEEL's highly progressive spring rate in radial compression can provide the vehicle's spring suspension in high mobility applications. To this end the LOOPWHEEL's edges may be reinforced by segmented steel links which can provide engagement with the teeth of a hull-fixed drive sprocket, Fig. 2, and with a swing arm mounted idler sprocket. Any jounce or rebound motion of the LOOPWHEEL results in a lengthening or shortening of the ellipse's major axis and in a corresponding swing arm motion.

A typical cross section of the original design is shown in Fig. 3. For increased load-carrying capacity two filament-wound composite cores are nested inside each other, separated by a strain-isolating layer. Steel bands span the cores from edge to edge to hold the sprocket-engaging segmented hardware in place. A rubber tread is vulcanized to the outer core for both traction and protection.

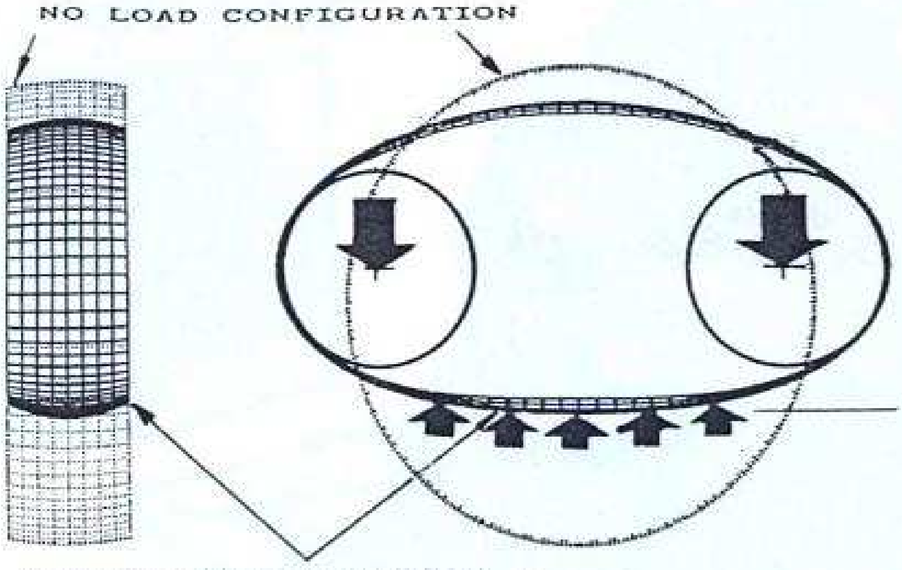
1.2 Low-Cost LOOPWHEEL Suspension

In applications where long spring travel is not required as in farm operations the vehicle loads may be transmitted to the LOOPWHEELS directly through two inner wheels (idler or drive wheels), Fig. 4. Large side forces are transmitted from the barrel-shaped wheels to the LOOPWHEELS by rubber rims extending inward toward the wheel axis, Fig. 5. Limited vertical spring deflection is provided by the LOOPWHEEL's inherent elasticity in the lower section.

2. FIELD TEST RESULTS OF 1.4-TON HIGH MOBILITY PROTOTYPE

For a first field demonstration of LOOPWHEEL suspension characterisics at modest cost a small tracked vehicle, the experimental Amphibious Infantry Support Vehicle (AISV) built by FMC was converted into a 4x4 LOOPWHEEL Development Vehicle (LDV), Fig. 6a, b. The field tests were conducted and documented by the US Army Engineer Waterways Experiment Station, Ref. 3, 4. For comparison purposes both the tracked AISV and the 4x4 LDV were tested over identical cross country courses. The LOOPWHEEL's longer spring travel, the terrain-smoothing effect of their stiff foot print and their very low unsprung mass resulted in substantial improvements in ride qualities as evidenced in the plot in Fig. 6c. From 53 to 130% higher cross country speeds can be achieved with the LOOPWHEELS before the same critical vertical acceleration levels as for tracks are reached where 6 watts of absorbed power at the driver station was used as acceleration limit. Frequent LOOPWHEEL derailments during the early tests were eliminated by addition of follower rollers, Fig. 6d for both drive and idler sprockets to assure permanent engagement. The major deficiencies revealed during the field tests were rapid fa-

FIG. 4. LOW COST SUSPENSION CONCEPT



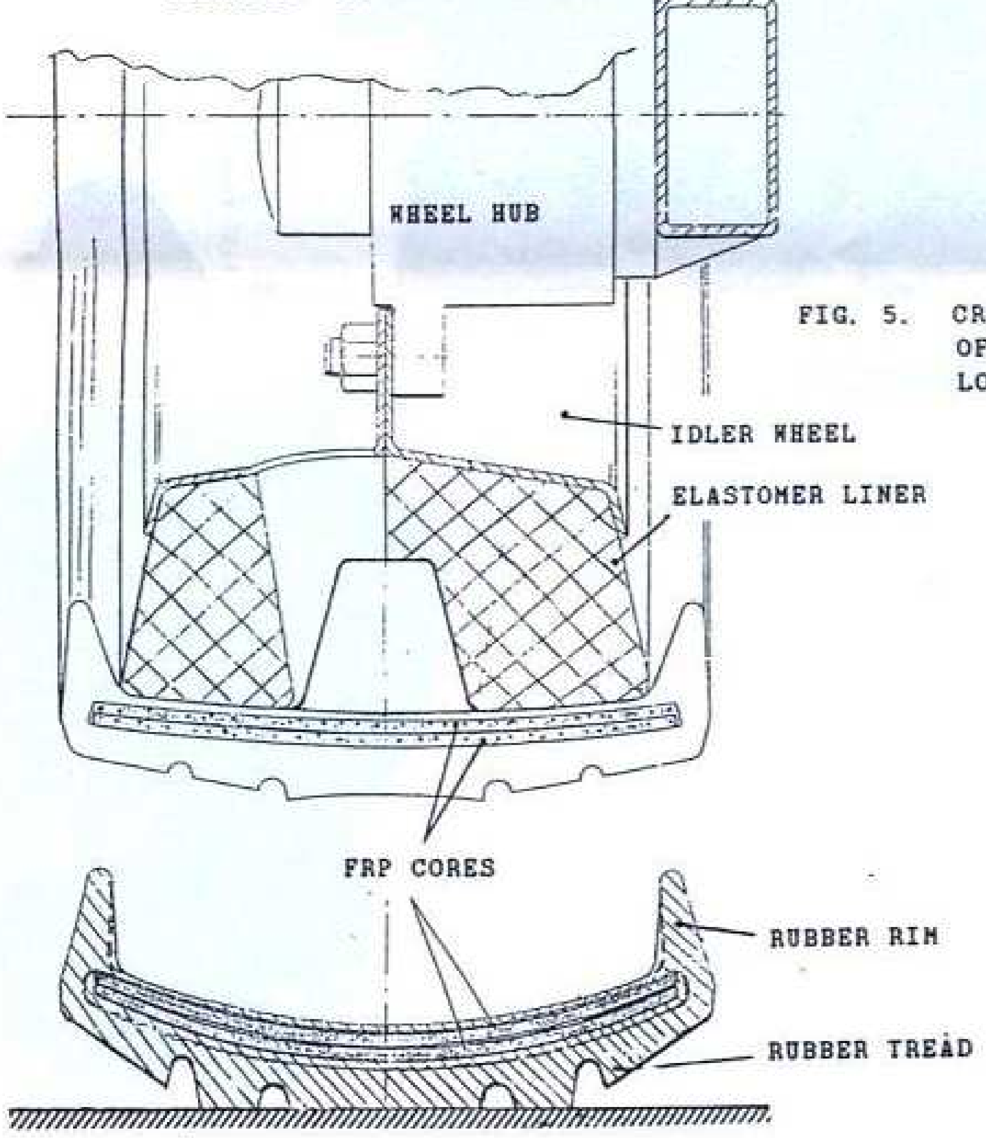
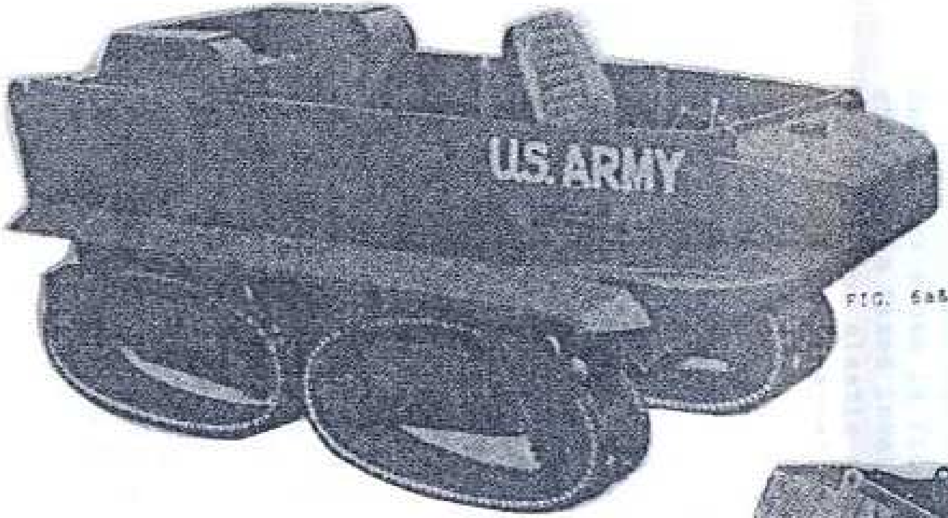


FIG. 5. CROSS SECTION OF IDLER AND LOOPWHEEL



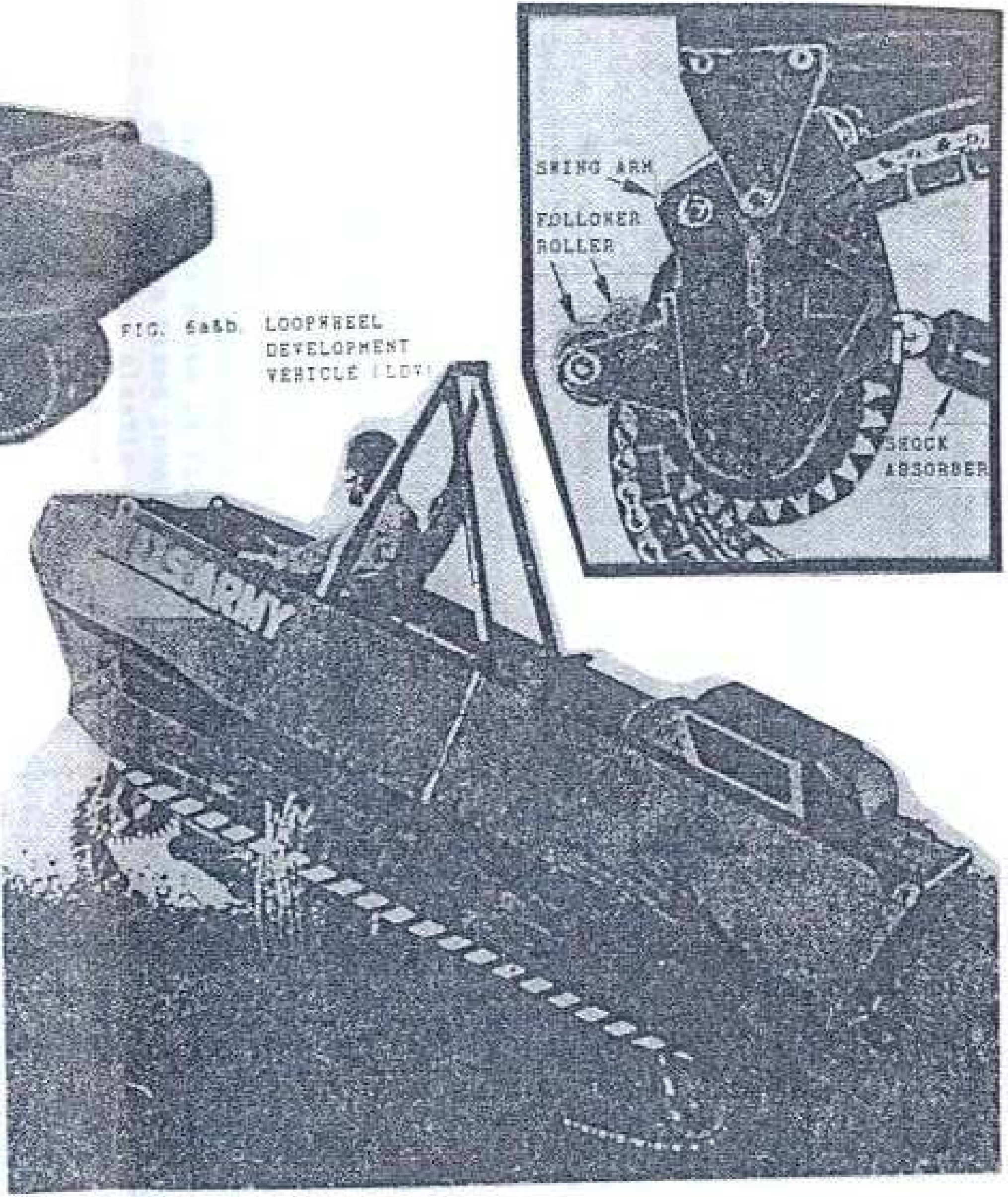


FIG. 6a&b. LOOPWHEEL DEVELOPMENT VEHICLE (LDV)

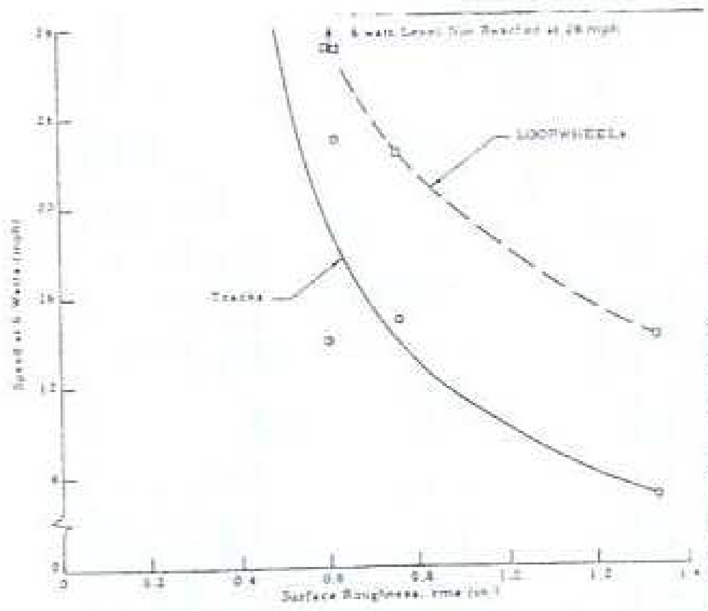


FIG. 6c. ASV Tracked vs LOOPWHEEL Performance on Cross Country Courses of Various Surface Roughness

tigue and high rolling resistence of the LOOPWHEELS, which led to a redirection of the original development plan: Instead of a conversion of an M 113 personnel carrier acceptable durability and rolling resistence levels had to be achieved first.

By 1983 the life time of LOOPWHEEL test articles manufactured in an improved proprietary process had reached between 7 and 10 million revolutions in dynamometer testing without delamination and with no more than 30 mm loss of available spring travel, Ref. 5. This represents 22 000 to 32 000 km durability for the LDV or 35 000 to 50 000 km for larger size M 113 LOOPWHEELS. Selection of better materials for loop core strain isolation and other engineering changes have brought rolling resistence down to approximately 5% of vertical load.

3. NEW DESIGN AND APPLICATION OPTIONS

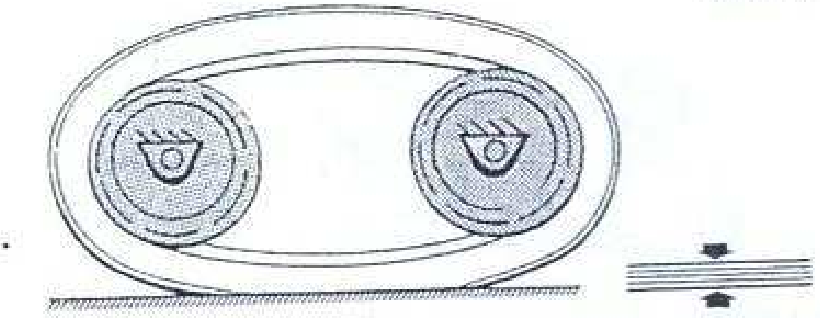
3.1 LOOPWHEEL Suspensions For Trailers

In recent independent studies various attractive new application areas were identified. The low-cost LOOPWHEELS of Fig. 5 appear well suited for farm and forestry trailers. Two simple suspension concepts are shown in Fig. 7. The idler wheels may be mounted to the chassis in fixed locations or on a pivoting tandem axle, which may be rigid or elastic as shown. For higher road speeds and reduced tread wear a pneumatic LOOPWHEEL configuration is under study in which a belted tire of very low height-to-width ratio would replace the solid rubber tread around the LOOPWHEELS. A LOOPWHEELed trailer with tandem axle suspension, Fig. 8, would replace tandem tires of size 19"width x 17"rim dia. and wheel base under 1 m and could lower ground contact pressures by approximately 50% at a similar overall envelope for the two tires or the single LOOPWHEEL.

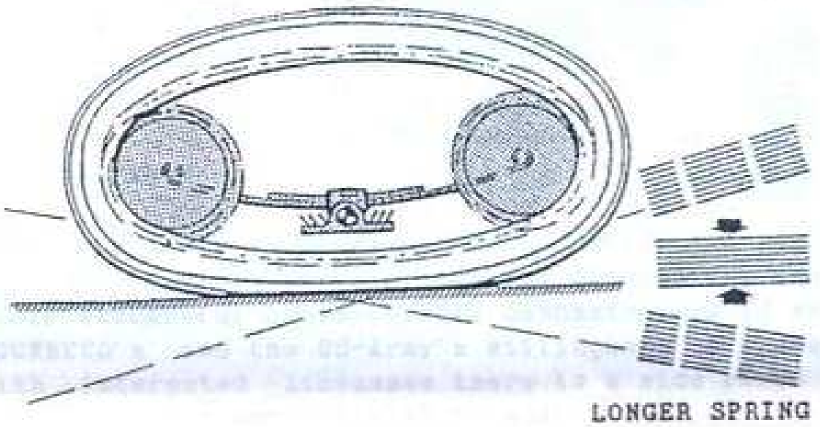
3.2 LOOPWHEEL Suspensions For Motorized Vehicles

Three driven suspension configurations of increasing complexity and agility are shown in Fig. 9a through c. In all cases the drive train is kept simple by hull-fixed location of the drive sprocket. For low-speed applications as in agriculture configuration "a" offers the lowest cost and limited spring travel by hull-fixed installation of all wheels and the top center guide roller. The LDV-type suspension "b" offers substantially more spring travel and active damping by the swing arm mounted idler sprocket and a set of 4 upper load and follower rollers. The highest degree of mobility is achievable by concept "c", which adds limited pitch motion to the LOOPWHEEL suspension "b". The idler wheel carrier may be pivoted around the center mounted drive sprocket or about a separate trunnion below.

FIG. 7. LOW COST SUSPENSION CONCEPTS

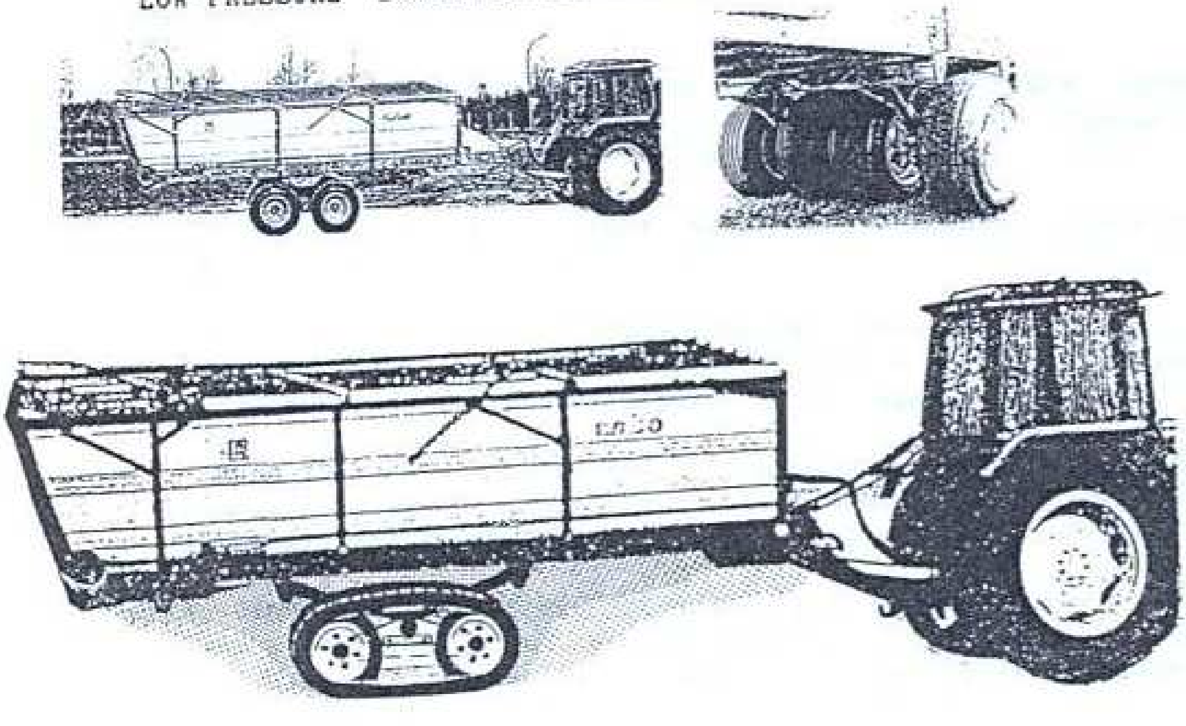


SHORT SPRING TRAVEL



LONGER SPRING TRAVEL

FIG. 8. TYPICAL FARM TRAILERS AND PROPOSED LOW-PRESSURE LOOPWHEEL SUSPENSION



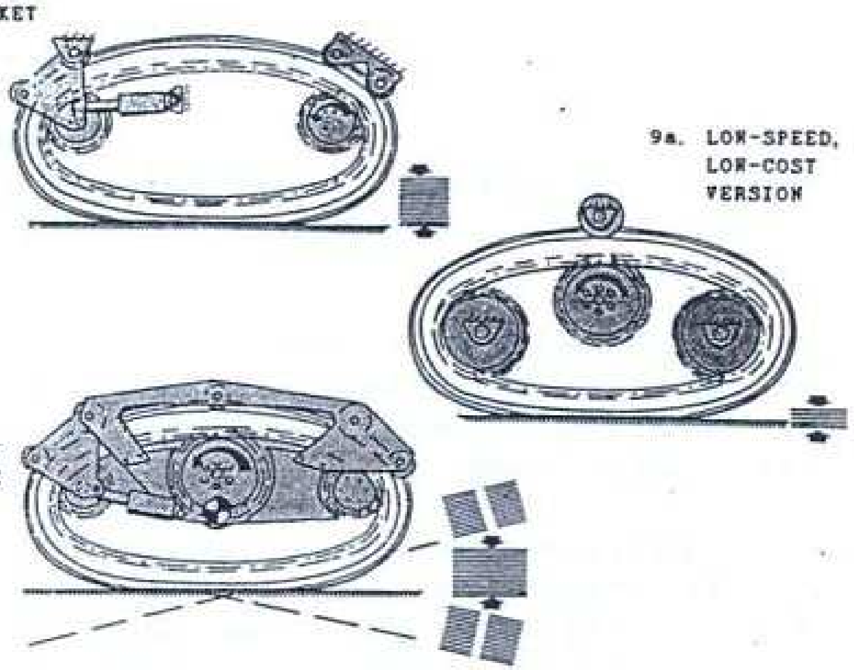


FIG. 9. ALTERNATE SUSPENSION CONCEPTS WITH HULL-FIXED DRIVE SPROCKET

9b. HIGH-MOBILITY VERSION WITH ACTIVE DAMPING

9a. LOW-SPEED, LOW-COST VERSION

9c. VERY-HIGH-MOBILITY VERSION WITH FREE PITCH ROTATION

4. CONCLUSION

After LOCKHEED's successful development of a manufacturing process for very durable yet light-weight filamentary composite LOOPWHEELS, their successful cross-country demonstration in small scale and with LOCKHEED's and the US-Army's willingness to share this technology with interested licensees there is a wide range of opportunities from low cost agricultural to most demanding high mobility applications which can take advantage of the LOOPWHEELS' potential as a smooth-running, light-weight mobility concept with integral spring suspension, large foot print and excellent obstacle negotiation.

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ARTICULATE TRAIN VEHICLE OF MULTI-USAGE ON ROUGH TERRAIN AND STEEP SLOPES

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Abstract

The articulate train vehicle was developed for the usage of maneuverability in overriding mounds or narrow ridges and of anti-overturn stability on steep slopes. This is the train of three component flames coupled articulately.

The articulate veering mechanism was designed to realize the two degrees of freedom, the vertical and the horizontal, and composed, three points hitch likely, of two oil-hydraulic cylinders hinged universally to component flame and one universal hinge set at top-link-like position. If both oil-hydraulic cylinder is given equal displacement of piston, the vertical veering is supported, and if the one is given larger displacement and the other smaller, the horizontal is supported.

This presentation reports the trial vehicle itself, its performance and the micro-computer assist on controlling the artiqulate veering angles in which each cylinder piston displacement is automatically calculated from set-values of veering angles and the rear articulate veering angles are controlled to follow the front veering angles.

Design Concept

As shown in Fig. 1, the proper operation of articulate veering angles enables traveling on various sorts and conditions of rough terrain. When the vehicle overrides a stump (b), a mound (c-1, c-2) or a log laid on the ground, the front articulate veering is controlled as climbing on and the rear articulate veering is controlled to follow the front veering angle with the time delay corresponding to the time required for traveling the distance between