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18. MODERN MECHANISMS MAKE MANLESS MARTIAN MISSION MOBILE -- SPIN-OFF SPELLS STAIRCLIMBING SELF-SUFFICIENCY FOR EARTHBOUND HANDICAPPED

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SUMMARY

Sponsored by NASA at Rensselaer Polytechnic Institute in Troy, New York, under Mission-Hardware Research Grant No. NGL 33-018-091, an annually changing group of undergraduate and graduate students under Dr. Sandor's direction have developed concepts for three wheel chairs, progressively improving designs of a proposed unmanned roving vehicle for the surface exploration of Mars and, as a spin-off, have generated a concept for a stair-climbing wheel chair. The mechanisms employed in these are described in this paper. The Mars mission is envisioned using the booster rockets and aeroshell of the Viking missions.

INTRODUCTION

Rensselaer Polytechnic Institute's (RPI) first concept was a four-wheeled dragster-like rover with the weight of a single payload package carried largely by the driven rear wheels (refs. 1-5, 8, 9, and 11). The undriven front wheels, which were well ahead, served for "wagon steering" and for obstacle detection. In case one or both front wheels dropped in a crevasse or over a ridge, the vehicle would stop and perform an emergency maneuver extricating its front end from the obstacle.

The wheels were a new RPI design: "toroidal" all-metal elastic wheels with crosswise hoop-spokes hinged to, but spaced apart from the flexible, grousered rim, which provides for a large footprint and avoids "stone-crushing" between rim and spokes (refs. 6, 7, and 12).

The second-generation vehicle could be folded to about two-thirds of its length for launch, with the payload at one end.

MECHANISMS OF THE MARS ROVER

RPI's present third-generation Martian Roving Vehicle (MRV) design is a four-wheel, single payload vehicle. Its demonstration model is shown in the folded "launch-and-land" configuration in Figure 1. When fully deployed, approximately 70% of the weight is carried on the driven rear wheels, assuring good traction.

To fit inside the existing Viking aeroshell, the vehicle is much smaller in the folded configuration than in its roving mode. This collapsibility allows a relatively large volume for the payload of the vehicle and a larger vehicle wheelbase and wider track than would otherwise be possible. Once on the surface of Mars, the vehicle must be able to deploy itself into the roving configuration. As will be seen, this is accomplished by the use of motor and gear assemblies which are used for other purposes during the vehicle's roving phase. Thus no additional weight and complexity is required for self-powered deployment.

RPI's MRV is capable of raising and lowering the payload and changing the payload attitude by the use of two motor-gear assemblies within the vehicle. On the demonstration model, each of these consists of an internally geared permanent-magnet "pancake" motor working with a worm-and-gear pair (Fig. 2). These two assemblies control rotation between the front section of the vehicle and the payload box, and rotation between the rear struts and the payload box. The rear struts are rotated by a torsion bar running across the payload box, keyed at the center to the smaller worm gear in Figure 2 and driven by a worm mounted in bearings attached to the gearbox floor. Each half of the torsion bar provides elastic suspension for its respective rear strut. The front section of the vehicle is rotated by a split torque-tube concentric with and surrounding the rear-strut torsion bar. The right and left sections of the tube leave room for the worm-gear mounted in the middle on the torsion bar. A rigid inverted U-shaped crossover piece connects these two half-tubes (Fig. 2), lending torsional rigidity to the assembly of the right and left tubes. Both half-tubes are driven simultaneously by a worm-gear mounted to the right side of the U-shaped crossover as shown in Figure 2.

When roving, directional control is accomplished by "wagon steering" of the front axle, which rotates about a single vertical axis at its center (Fig. 3), turned by a worm-and-gear pair powered by an internally geared permanent-magnet motor. A precision potentiometer senses the position of the front axle and feeds this information back to the steering and rear-wheel drive control systems of the vehicle. The individual rear-wheel drives adjust their speeds to match the turning radius. When the front axle is turned 90° from its straight-ahead position, the rear wheels are driven in opposite directions and the vehicle can swing around with the center of turn at the mid-point between the two rear wheels.

Four-wheel ground contact on rough terrain is assured: the front axle swings about a horizontal pivot. Its swing is centered and limited by steel bands and leaf springs (Fig. 3).

The entire front axle and steering system is mounted on a horizontal-transverse shaft and can be rotated to any position within an arc of 240° by a motorized worm-and-gear pair (Fig. 3). This extra rotation (so-called "flipover") capability enables the front axle to flip to an "up" or "down" position and keep its steering [illegible] the attitude of the front struts.

The front and rear [illegible] axle flipping system assist in deploying the vehicle [illegible]-land configuration. They also enable the vehicle [illegible] flip-over maneuver. In addition, they provide a [illegible] the vehicle to climb up a step which is higher than one [illegible].

As can be seen in Figure [illegible], which [illegible] at the beginning of the deployment sequence, the front strut [illegible] to permit folding. The locking mechanism chosen to keep the [illegible] deployed position is a spring loaded locking plunger [illegible], which fits within the hollow square-tube front-strut [illegible]. The plunger is automatically released and locks when the [illegible] articulation reaches a straightened-out position (Figs. 5b and [illegible]).

THE DEPLOYMENT [illegible]

To deploy the front section, the [illegible] attitude motor (Fig. 2 front) is utilized to drive the rear section of the forward strut forward while the front wheels roll forward on the ground (Figs. 7 and 8). This straightens the front struts to a position where the automatic latching devices (Fig. 5) lock the articulation in the straightened-out position (Fig. 9).

The front axle flipping motor then [illegible] between the front struts and the axle to its normal attitude with the steering axle vertical (Fig. 3).

To deploy the rear wheels, the [illegible] rear-wheel propulsion drive motors are actuated in the forward direction. As the rear wheels roll on the ground, they straighten out the articulated rear struts (Fig. 10), while the payload box still rests on the ground. Once straightened out, the rear strut articulation hinges are locked in the extended position (Fig. 11).

On the demonstration model, commands for deployment and maneuvering are sent to the vehicle from [illegible] manned console [illegible] radio link. They are received on the demonstration model by an [illegible] radio receiver and control system. The deployment commands necessary to unfold the vehicle and make it ready for roving are sequences of commands normally used in roving. For example, to deploy the [illegible] wheels, the rear torsion bar motor is commanded to drive the rear wheel [illegible]ward into contact with the surface, same as would be used to raise the payload. Then both rear wheels are commanded to roll forward at low speed, thus swinging the hinged part of the rear struts forward and locking them into position (Figs. 10 and 11).

By driving both front and rear struts downward, the payload is now raised off the ground and the vehicle becomes fully operational (Figs. 12 and 13).

EMERGENCY MANEUVER

A useful feature of the RPI-MRV is its ability to extricate its front wheels from a pit or depression. If the front wheels are driven over the edge of a cliff, the vehicle lifts both front and rear sections off the ground while the bottom of the payload rests on the ground. The front and rear wheels are interchanged by swinging the struts overhead (Fig. 14). Once this interchange is completed, all four wheels are once again on solid ground, because the rear struts are much shorter than the front section, and the vehicle can drive away from the edge of the cliff.

THE RPI WHEEL

The RPI-MRV's all-metal elastic toroidal wheel is shown in Figure 15 (refs. 6, 7 and 12). Large footprint and elasticity of suspension is achieved by hinged connections between the hoop-shaped spring spokes and the flexible rim.

A "SPIN-OFF": STAIR-CLIMBING WHEEL CHAIR

One of the most interesting spin-offs of the RPI-MRV Project was the lopment of a design concept for a stair-climbing wheel chair (refs. 13- . At a previous presentation concerning the Martian Rover (ref. 3) a member of the audience suggested the possibility of adapting its unique undercarriage to a stair-climbing wheel chair. The suggestion was welcomed, and resulted in a preliminary proposal in the form of a paper submitted to the Medical Society of the State of New York (ref. 15). The publication of that paper (ref. 14) resulted in numerous inquiries directed to its author, Dr. G. N. Sandor. Noting this interest, Dr. Sandor took this idea to one of his classes and proposed that the class take on the development of the design concept for the "stair-climbing wheel chair" as a term project. The response was enthusiastic, and work began in February 1974.

The idea of a central pivot and four struts was adopted directly from the rover. The flexible wheel (Fig. 16A), however, was deemed impractical for stair climbing. The problem encountered was one of approaching the first step. It was felt that the step would have to touch the wheel somewhere below the point at which a tangent to the wheel make a 45° angle with the ground. Such a wheel would have a minimum diameter of about 30". Four 30" wheels did not seem practical. An alternate solution was to provide any desired attack angle by means of a track (Fig. 16B). At the right side of this figure there would be internal guide wheels at top and bottom. Changing the relative positions of these two wheels allows generation of any attack angle desired. Figures 16C, 16D and 16E represent three other solutions which were proposed. Figure 16C is the "lobed wheel." This particular shape is one used on a prototype stair-climbing wheel chair built several years ago. Figure 16D is the "cam wheel." The cam, on the left, contacts the step and lifts the wheel up behind itself, then folds away and allows the wheel to roll. Figure 16E represents three versions of a dual-wheel concept which arose halfway through the project. In the first version, the two wheels turn about their own axes and also about the pivot between them, similar to a lobed wheel with 2 lobes. In the second version, the auxiliary pivot is moved out from between the wheels. The rightmost wheel would rise, engage the next higher step, lift the whole chair one step, roll forward, and repeat. Version three has the same action, using linear actuators or hydraulic cylinders to provide the lifting action. In evaluating the mechanisms, "A" was considered too big, and "C" was deemed unsuitable for varying stair sizes. "D" and "E", although of reasonable size and excellent adaptability, were thought to be much more complex than a track and were held in reserve in case a suitable track brought on too many complications of its own. It was decided that the individual inventors (student members of the class) would pursue the concepts represented by Figures 16D and 16E, and the rest of the group would set to work on a track-type stair climber, with two 3 to 4 inch wide tracks, one on each side.

At this point a 1/6-scale plastic and balsa wood model was constructed, resembling Figure 17. Using this model as a rough guide, eleven teams were formed to tackle various aspects of the design. Some of the best technical solutions came from team members who were also "Martians," that is, involved in the Martian Rover Project. The resulting design is shown in a simplified form in Figure 18.

DESIGN CONCEPT OF THE WHEEL CHAIR

The fully motorized chair would be 10.1 centimeters (42 inches) long and 6.4 centimeters (25 inches) wide overall, about the size of present conventional wheel chairs. Seat height would be variable by the occupant at will from the height of a normal chair to a height at which a person in the chair would be at eye level with a standing person. This restoration of the vertical dimension of movement is highly desirable to the disabled, especially when he confronts a pay phone, supermarket, library, or overhead kitchen cabinets. Vertical movement is accomplished by pivoting the main struts. In doing so, the inner, or level-travel wheels lose contact with the ground and the chair rests on the stable wide stance of the tracks.

CLIMBING STAIRS

In public buildings, stair climbing between floors is usually made unnecessary by elevators. Getting into public buildings and private homes is another matter, however. There is invariably a curb between the parking lot and the entrance sidewalk and building entrance. The more athletic wheel chair users can jump curbs, but two or three steps might as well be a locked and barred gate to a conventional wheel chair user. The stair-climbing chair will tackle 5 or 6 inch curbs head on. Stairs will be climbed backwards, to keep a low center of gravity.

DESCENDING STAIRS

Descent gives rise to the wheel chair user's greatest apprehension and fear of falling. To overcome this, the chair will face downhill giving good visibility, which is reassuring as well as necessary in avoiding loose objects. To assure sufficient stair clearance, two four-bar mechanisms were proposed which retract the inner wheels when the chair support strut is moved fully rearward for stair climbing or descending. The mechanism for retracting the front castered wheels, shown schematically in Figure 18, is detailed in Figures 19A and 19B. Figure 19A represents level travel and 19B shows the wheel retracted as in Figure 18.

DRIVE SYSTEMS

Two separate drive systems were incorporated. The track-drive motors will be hub-mounted in the forward track guide wheels and have manual shoe type brakes. The level drive, in the configuration of Figure 17, would be powered at the two rear wheels, steering by varying the speed ratio of these wheels. By driving the two rear wheels in opposite directions, a turn in place can be accomplished.

The strut pivots of the Martian Rover used nearly self locking worm gears. To keep down weight and expense, while improving efficiency, a gear-motor ("M" in Fig. 19C) and spur gear combination was found which met the torque and power requirements. The motors would fit inside the aluminum box beam struts (Fig. 19C). A small, low-torque brake, mounted on the free end of the motor rotor shaft, would provide locking action.

Chair leveling is to be accomplished by the combined motions of the chair-support strut and a motor-driven ballscrew connecting the side of the chair to a pivoted nut on the chair support strut (Shown in Fig. 18).

It is thought that the chair itself, the speed control system and the power supply could be adopted with minor alterations from present electric wheel chairs. The track, struts, chair-leveling mechanism and wheel retractors are all unique items which need to be tested in a prototype to confirm estimated power, strength, and dimensional aspects.

DYNAMIC AND HUMAN DESIGN

In addition to the purely mechanical aspects of the design, some work was done evaluating the dynamic stability of the complete vehicle with the turning radius, speed and surface inclination as parameters. This work governs optimization of the wheel base and wheel track dimensions.

The human side of the problem was considered early in the project and was a governing consideration throughout. Contacts were made with professional rehabilitation personnel, potential vendors and potential users. These contacts showed that once a prototype is made, a large effort must be devoted to assuring adaptability of the device to a particular user's abilities and disabilities. Careful consideration must be given to operating characteristics and aesthetic appearance, thus facilitating acceptance by the user as well as by the general public.

The idea of a stair-climbing wheel chair, while not unique in itself, has inspired some very original mechanisms which hopefully may make this stair climber the first to gain wide acceptance. In rehabilitation work, a distinction is made between the disabled and the handicapped. A disability is only a handicap to the extent that it prevents a person from being a full participant in society. A handicap is imposed and may be removed or overcome. The purpose of this wheel chair would be to remove such handicap.

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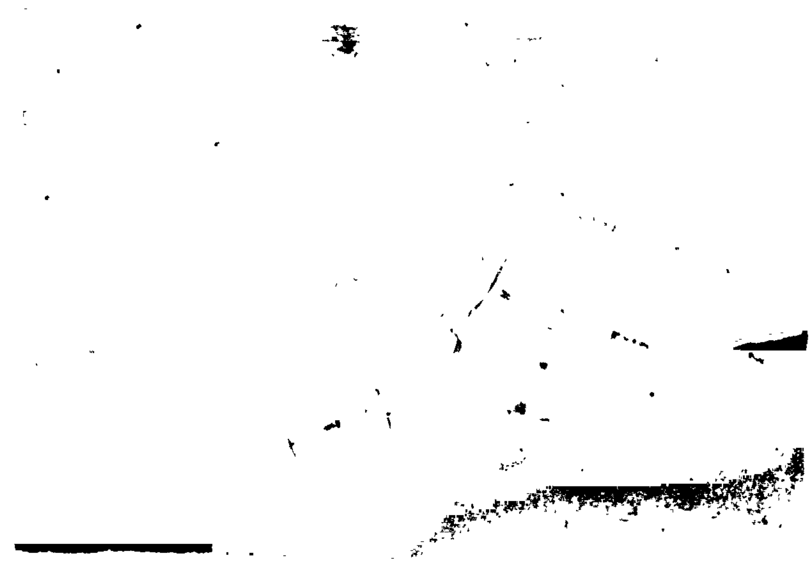

Figure 1. RPI MRV demonstration model in folded "launch and land" configuration.

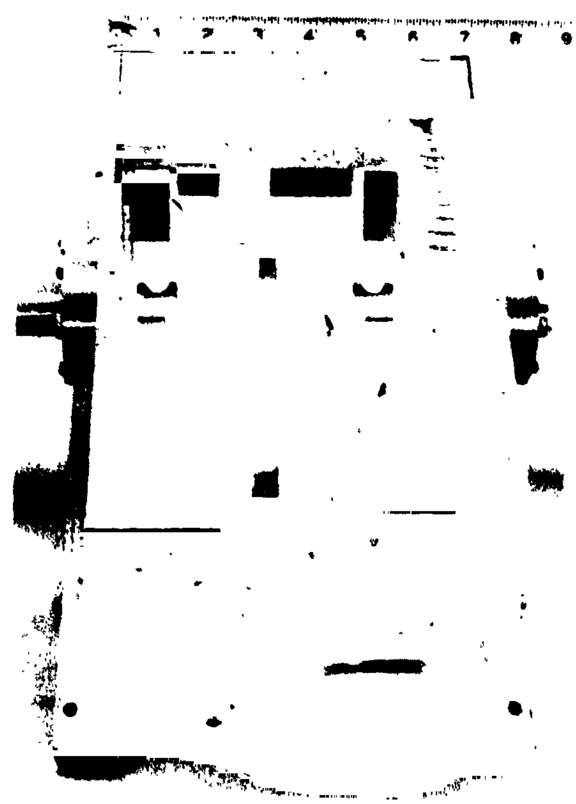

Figure 2. Strut-rotation gearbox in center of payload box. Rear strut worm gear at left, front strut gear at right, pancake motor in front. Similar pancake motor, hidden in back, rotates rear struts.

Figure 3. Front end of the RPI MRV with "flip-over" worm and worm gear (left) and steering gear (center).

Figure 4. Side view of the MRV demonstration model in the first stage of deployment from its folded launch-land configuration, showing articulation of front struts. The front wheels are at the right.

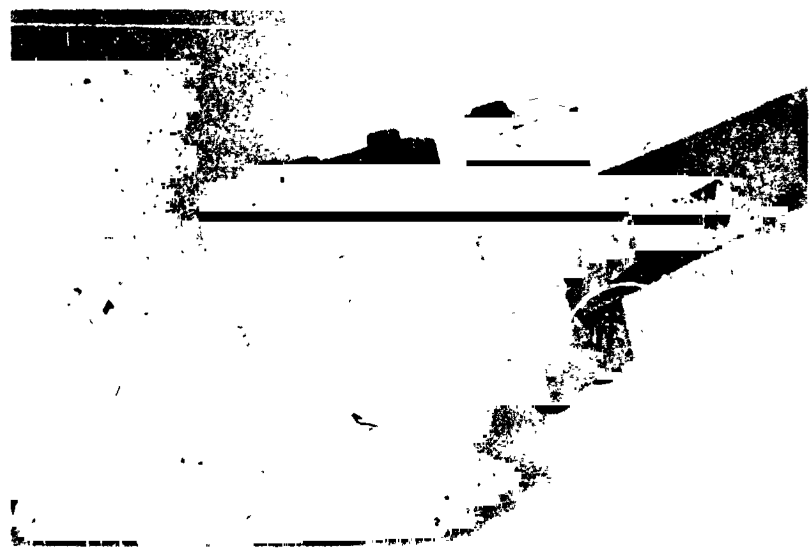

Figure 5a. Close-up of mechanism in unlocked position showing spring loaded locking plunger and release member.

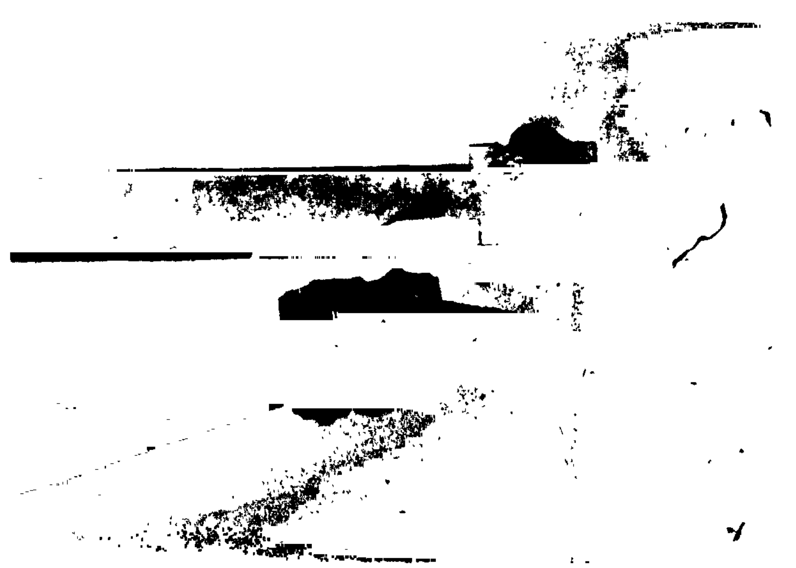

Figure 5b. Front strut articulation and locking mechanism in locked position (top) and before locking (bottom).

Figure 6. The front strut articulation hinge in the straightened-out position, locked by the square plunger inside the square-tube frame member.

Figure 7. While the payload box rests on the ground, deployment starts by rotating the rear section of the articulated forward strut clockwise as shown here.

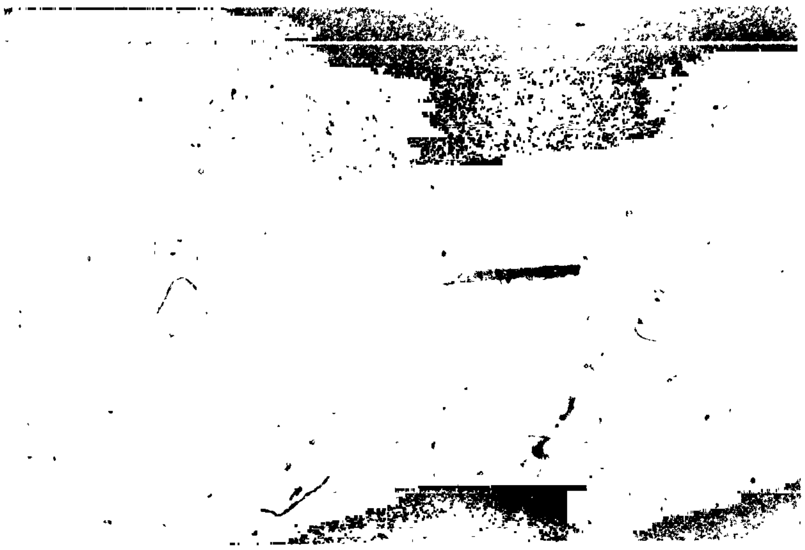

Figure 8. With the payload box still on the ground, the front s.ruts are approaching the locking position while the front wheels roll on the ground in the course of deployment.

Figure 9. The MRV during deployment, shown just after the fron. strut articulation has been locked in the straightened-out position. The payload box still rests on the ground.

Figure 10. The RPI MRV in the process of "walking" the rear wheels from folded into deployed position. The payload box is still resting on the ground.

Figure 11. After completing the rear wheel deployment, the MRV is ready to lift its payload box off the ground.

Figure 12. The front struts have been rotated downward, lifting the front of the payload box off the ground.

Figure 13. Rear struts having been rotated downward, the payload box is off the ground and the RPI MRV is fully deployed in the roving configuration.

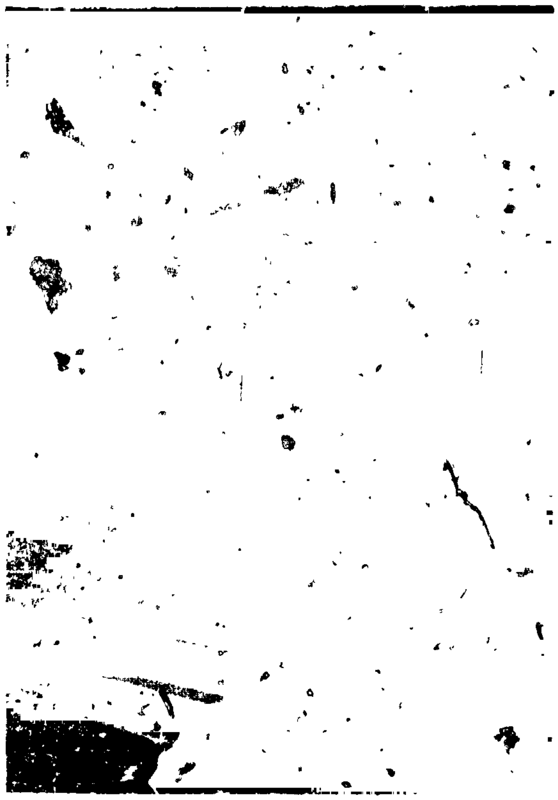

Figure 14. The RPI MRV executing an emergency maneuver. The front and rear struts are exchanging positions, clearing each other as they pass overhead.

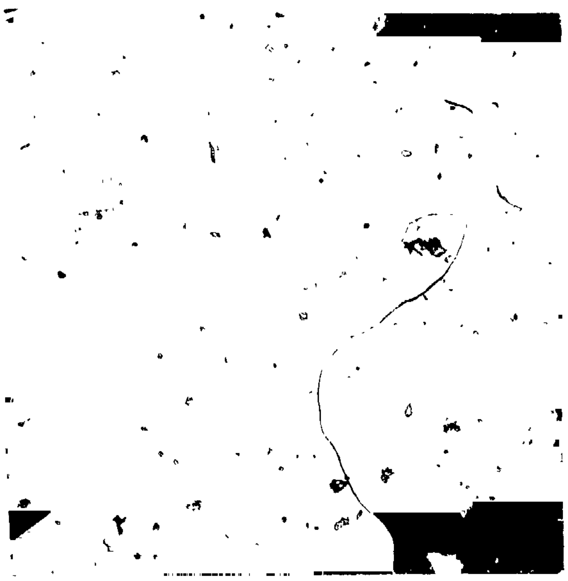

Figure 15. The RPI "all-metal elastic" toroidal wheel.

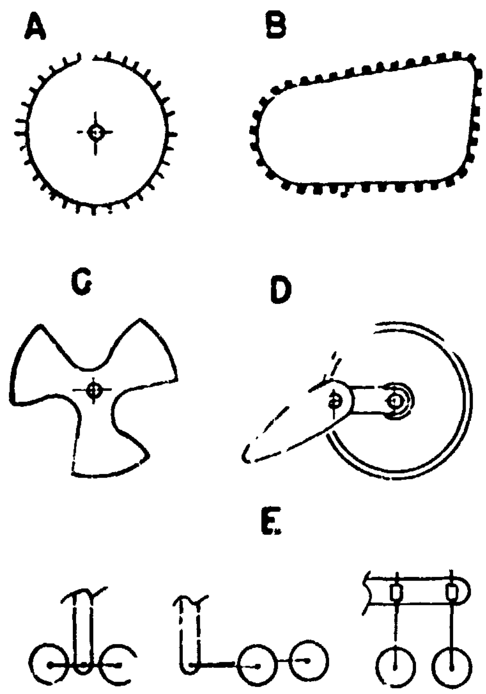

FIGURE 16

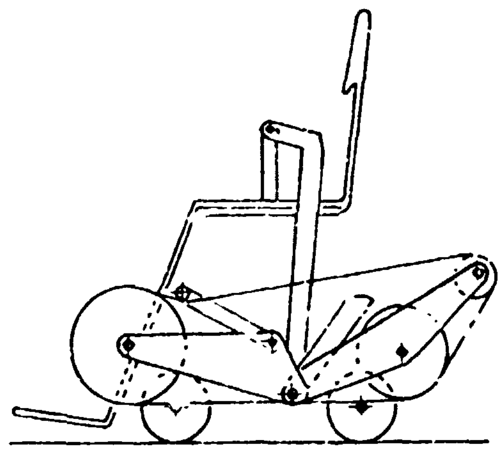

FIGURE 17

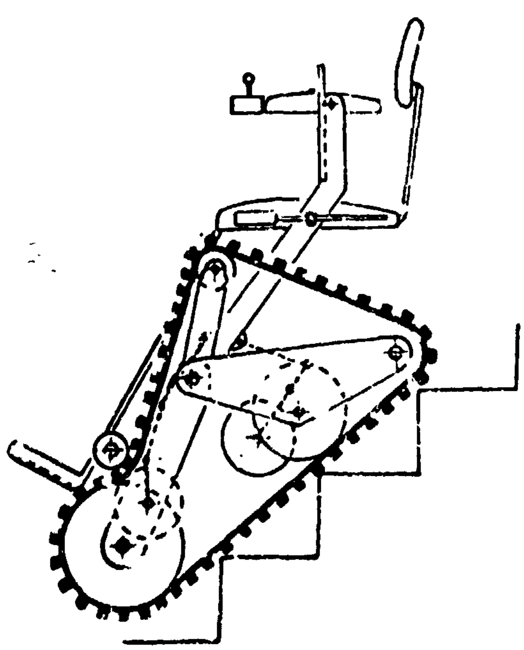

FIGURE 18

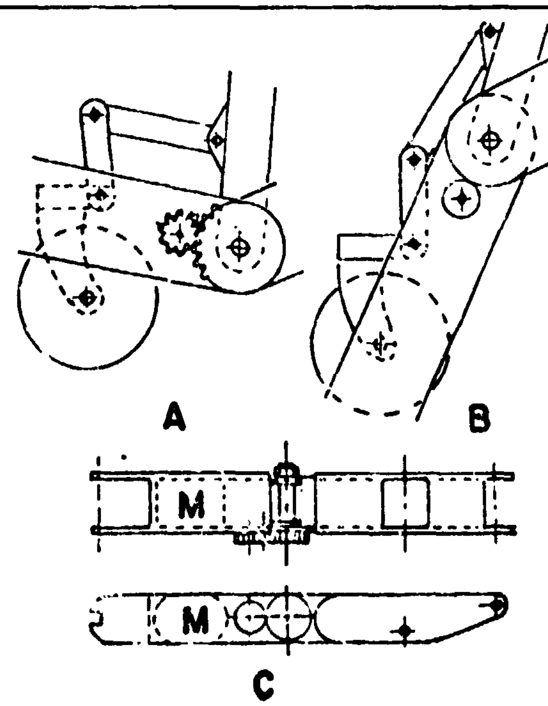

FIGURE 19

Figures 16 to 19. RPI's stair-climbing wheel chair design.