A CONCEPT OF THE ALL-ELECTRIC PRESSURIZED ARTICULATED TRIAD MARTIAN ROVING VEHICLE

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To the Living Memory of Prof. Dr M. Gregory Bekker

ABSTRACT

The extremely high-mobility extraterrestrial all-electric pressurized articulated triad **Martian roving vehicle** (MRV) "Bekker" type will be designed for the usage of maneuverability in overriding mounds of narrow ridges and anti-overturn stability on steep slopes. This MRV will be the train of two or three **vehicle-units** (VU) propelled electro-mechanically and coupled articulately with the aid of the mechatronically **neural network** (NN) **fuzzy-logic** (FL), that is, **neuro-fuzzy** (NF) mechatronically controlled articulation **inter-unit** (IU) electromechanical couplers (coupling joints) and/or steering mechanisms. The **drive-by-wire** (DBW) **four-wheel drive** (4WD) **middle-unit** (MU) will operate as single one, that is, like a **lunar roving vehicle** (LRV) "Bekker" type, as far as its mobility permits. The added DBW **two-wheel drive** (2WD) front- and/or **rear-unit** (RU) should not impair normal operation. The two or three VUs will be coupled when the **human- and/or telerobotic-driver** (H&TD) anticipates that the single 4WD MU cannot handle a certain terrain or obstacle, or failing that judgment, after a 4WD MU becomes immobilized.

INTRODUCTION AND BACKGROUND

Mars is the planet most like Earth, and for that planetary scientists have long speculated about the possibility of life on the Red Planet. All unmanned landers sent to Mars in the past found no signs of biological activity. They photographed a Red Planet that is dry, cold, and pocked with craters, and did not gather enough data to determine whether the Red Planet has sufficient reserves of water, carbon dioxide, and nitrogen to make terra-forming feasible [16]. **Martian roving vehicles** (MRVs) could help provide the needed data. ***National Aeronautics and Space Administration*** *(NASA)* and ***European Space Agency*** *(ESA)* are currently involved with planning unmanned missions to Mars to investigate the terrain and process soil samples. In advance of manned missions, an essential large real-world problem involved in unmanned surface exploration on Mars is that of supporting autonomous maneuvering since **spread spectrum radio** (SSR) communication involves lengthy delays. It is anticipated that the specific target locations will be designated for sample gathering. In maneuvering autonomously from a starting position to a target position the MRV will need to avoid a variety of obstacles such as boulders or troughs that may block the shortest path to the target. The physical integrity of the MRV needs to be maintained while minimizing the time and distance required to attain the target position. **fuzzy logic** (FL) lends itself well to building reliable mechatronic control systems that function in the presence of uncertainty or ambiguity [5,9].

Whether it is controlling the navigation of the MRV on Mars, *NASA* and *SEA* missions in the 1990s cannot enjoy an increased level of autonomy without the efficient imple-mentation of expert systems [5], [7].

A design process of the MRV ought to be conducted as stepwise refinement along three stages, i.e., conceptual, fundamental, and detailed design. As a general model of design activities in these design stages, metamodel will be proposed. Based on the model, design knowledge representation ought to be discussed. Since a design object (MRV) is constrained by the physical laws of the real world, knowledge about a physical world, i.e., ontological knowledge, is indispensable to design a new artifact. Metamodel mechanism, which allows an **intelligent computer aided design** (ICAD) system to support a designer with ontological knowledge, ought to be presented. A physical feature library ought to be proposed as knowledge base of physical phenomena.

The first extraterrestrial unmanned wheeled **electric vehicle** (EV) landed on the Moon was **LUNOKHOD 1** that began its Earth-controlled travels on 17 November 1970. It moved a total of *10,54 km* (*6.54 miles*) on gradients up to $\pi/6$ (*30* °) in the Mare Librium and did become non-functioning until 4 October 1971 [21]. The fourth lunar landing mission, **APOLLO 15**, was launched on 26 July 1971. Modifications to the spacecraft permitted longer lunar surface stay time and additional scientific instruments in lunar orbit. On 30 July 1971, at 6:16 p.m. EDT, the astronauts landed at the Hadley Apennine site.

During *66 h 65 min* in stay on the Moon they explored the lunar surface, riding the first extraterrestrial manned wheeled **lunar roving vehicle** (LRV), for a total of *18 h 36 min*; collected approximately *77 kg* of surface samples; deployed geographical instruments; and described geographical features. The Pacific Ocean landing was made on 7 August 1971 [15]. The lunar travel speed and distance record was set by the **APOLLO 16**'s LRV with *17.9 km/h* (*11.2 mph*) downhill and *35,8 km* (*22.4 miles*).

Designers at *Boeing Defense and Space Group* have designed a new generation of LRVs and MRVs. For instance, the biggest prototype MRV has its total mass of approximately *9 Mg* [17]. Planetary researchers at *NASA's **Jet Propulsion Laboratory** (JPL)* in Pasadena, California USA, have designed a prototype of a pickup-size MRV that could be sent to Mars to retrieve rock and soil samples, but shipping such a large MRV would be expensive. For the same prize, *NASA* instead might send a fleet of smaller MRVs [16]. In recent tests, a *25.4 kg* (*56-pound*) prototype **ROCKY III** mini-MRV built at *JPL* crossed rough terrain in California's Avawatz Mountains - similar to terrain found at the **VIKING 2** site on Mars, says *Mr. Roger Beard**,** Manager of Rover Technologies* [16]. The '*two-foot-long*' prototype - **ROCKY III** mini-MRV. picks up samples with its manipulator arm. It is SSR-controlled and carries an **infra-red** (IR) video camera. But because it takes at least four minutes for SSR and TV signals to travel between Earth and Mars, a MRV would be programmed to operate autonomously. In September 1992, the **TITAN 2** rocket was carried onto the orbit of the **MARS OBSERVER** unmanned lander that made the stricter digital map of the Red Planet surface, and this lander has been designed at *NASA's JPL* in Pasadena, CA, USA. The extraterrestrial all-electric pressurized articulated triad **Martian roving vehicle** (MRV) "Bekker" type will be designed for the usage of maneuverability in overriding mounds of narrow ridges and anti-overturn stability on steep slopes. This MRV will be the train of two or three vehicle-units propelled electromechanically and coupled articulately with the aid of the fuzzy-logic mechatronically controlled articulation inter-unit electromechanical couplers (coupling joints) and/or steering mechanisms.

The author has been developing third gen-eration **ride-by-wire** (RBW) or **X-by-wire** (XBW) automotive mechatronic control systems as one of the major elements of his **Automotive Mechatronics** (AM) Program. The major efforts of the author's **research and development** (R&D) work reached the highest level of the design and construction on novel experimental proof-of-concept planetary gearless **electromechanic/mechanoelectric or vice versa** (E-M/M-E) steered and motorized/generatorized wire-mesh wheels with the **direct current-alternating current or vice versa** DC-AC/AC-DC macrocommutator E-M/M-E wheel-hub motors/generators applied to **drive-by-wire** (DBW) **all-wheel driveable** (AWD) propulsion and **brake-by-wire** (BBW) **all-wheel brakeable** (AWB) dispulsion mechatronic controls.

The basic flexible wire-mesh-wheel tire consists of one or several circular wire-mesh bands of high-strength filamentary composites with a slight transverse barrel-type curvature, which can take advantage of its potential as a smooth-running, High-mass mobility concept with integral spring suspension, large foot print and excellent obstacle negotiation. This paper also describes the design and construction of new concept planetary gearless E-M/M-E steered and motorized/generatorized wire-mesh wheels of the compact high-torque DBW AWD propulsion and BBW AWB dispulsion mechatronic control systems for the extraterrestrial all-electric pressurized articulated triad MRV "Bekker" type.

THE BEKKER TIRE

The never-enough-to-be-regretted Pole *Professor Dr M. Gregory Bekker* of the USA had taken a serious stab at conceiving the wire-mesh wheel. His design, a non-pneumatic metal wire-mesh wheel developed at *Boeing's Aerospace Group* in the USA, is claimed to have low rolling resistance, little external noise, and taut steering response. And although the MRV may appear to have four flats, the integral tire is puncture-free, so there's no need to carry a spare. Outwardly it looks like a super-extreme wire-mesh tire. Shown in the sectional drawing, the Bekker wheel is a bowl-like reinforced metal or composite wire-mesh molding with a steel hub [1,19]. The wire-mesh provides water drain-age, if any, to counter aquaplaning, as do small holes in the outer rim between the lines of the tread blocks.

Dr Bekker's design concentrates tire deformation from wheel-loading and terrain irregular-ities very near the terrain surface, in contrast to the thick air cushion of conventional pneumatic rubber tires. This benefits steering and cornering characteristics. In addition, the metal or composite wire-mesh tire has a square footprint that has about a *50 %* larger grip area than a usual oval one. In in-situ tests it has been measured rolling resistance at up *30 %.* lower than a pneumatic rubber tire. That is because its metal or composite material has much less internal damping than rubber, which absorbs considerable energy as it is repeatedly compressed and released.

Unfortunately, the lower damping of the metal or composite wire-mesh wheel causes tire vibration to reach the MRV body, creating high internal noise. To counter this, a modified **electro-rheological fluid** (ERF) or **magneto-rheological fluid** (MRF) **absorb-by-wire** (ABW) **all-wheel-absorbable** (AWA) suspension mechatronic control system ought to be fitted to the all-electric pressurized articulated triad **THREE-IN-ONE**^{TM} MRV "Bekker" type. Another problem is static deformation of the tire contact patch after extended parking, causing a bumpy ride until initial rotation and centrifugal force restore the normal circular shape. A different metal or composite material mix should solve that, was convinced Dr Bekker.

A new approach to on- and/or off-road mobility, taking benefits of circular and barrel-shaped filament-wound high-strength, corrosion-resistant and light-mass endless belts, that are wire-mesh tires driven by electromechanical/mechanoelectrical steered and motorized/generatorized wire-mesh wheels with the AC-AC or DC-AC/AC-DC macrocommutator E-M/M-E wheel-hub motors/generators **MAGNET ROTA™**, conceived and constructed by the author, may be applied to automotive **very advanced propulsion** (VAP) systems, and will be properly installed in an extraterrestrial all-electric pressurized articulated triad MRV "Bekker" type, and can combine the functions of spring suspensions and roads distribution over large foot prints in compact single-piece structures is developed at the *Thaddeus Kosciuszko Memorial Krakow University of Technology* in Krakow, Poland.

The same new approach was earlier developed at *Boeing's Aerospace Group* as the wire-mesh tire concept for a *45 Mg 4 _ 4* LRV built under *NASA. George C. Marshall Space Flight Center* in Huntsville, AL, USA contracts [1,8,13]. The concept was drawn from earliest attempts by Professor Dr M G Bekker who noticed the advantages of high-strength metals and composites and made proper use of the inherent spring move of such endless belts, that are wire-mesh tires [1], [2], [8].

The fundamental wire-mesh tire consists of single- or poly-band endless wire-mesh belt of high-strength, corrosion-resistant and light-mass filamentary composites with a slight transverse barrel-type curvature passing over wheel-rims, used to give MRV a good grip on soft or uneven surfaces. To this day the *NASA* is rating wire-mesh wheel suspensions among the primary mobility options for LRVs and MRVs [1], [2], [8], [12], [13], [15-17].

According to *M G Bekker and the others* [l], [2], [8], [18], [19] as the fundamental wire-mesh tire assumes a near-circular shape, distributing the load over a large ground contact area (foot print), when a vertical load is applied. The fundamental wire-mesh wheel's highly progressive spring rate in radial compression can stipulate the vehicle's spring suspension in high mobility applications, if properly suspended and guided. To this end the fundamental wire-mesh wheel's segmented edge protectors may be reinforced by steel links that can stipulate engagement with the rim of a hull-fixed wheel. Any jounce and/or rebound motion of the fundamental wire-mesh wheel results in a lengthening and/or shortening of the ellipse's major axis and in a corresponding swing arm motion.

The wire-mesh wheel's larger spring move, the terrain smoothing effect of its stiff foot print and its very low unsprung mass resulted in substantial improvements in ride qualities are evident. Fundamental wire-mesh wheel derailments may be taken away by steel hubs for front- and/or rear-wheels to assure permanent engagement.

Originally, mobile wire-mesh wheeled LRVs. had been developed for lunar purposes, and only during the past few years have they gained increasing significance with regard to Martian applications. In the beginning a conventional wire-mesh wheeled LRV built by *The BOEING Company, Aerospace Group* [1], [2], [8], [13] had been converted by the author into an *8 _ 8* wheeled pressurized articulated MRV "Bekker" type by installing eight electrically-powered steered and motorized/generatorized wire-mesh wheels, each of them with a DC-AC/ AC-DC macrocommutator E-M/M-E wheel-hub motor/generator, and thus increasing its mobility. Modern *8 _ 8* wire-mesh wheeled pressurized articulated triad **THREE-IN-ONE™** MRV, however, differ considerably from those early ones and have an extremely high mobility range.

EXPERIMENTAL PROOF-OF-CONCEPT
DBW AWD PROPULSION AND BBW AWB DISPULSION CONTROL SYSTEMS FOR MANNED AND/OR UNMANNED MARTIAN ROVING VEHICLE

In the manned and/or unmanned LRV & MRV field an example of study is represented by an experimental proof-of-concept electromechanical/mechanoelectrical DBW AWD propulsion and BBW AWB dispulsion mechatronic controls for an electrically-powered and mechatronically-controlled *8 _ 8* wheeled pressurized articulated triad **THREE-IN-ONE™** MRV "Bekker" type with extremely high mobility and guidability, including steerability, which. is conceived and designed by the author.

Figure 1 shows an overall view of the extraterrestrial all-electric pressurized articulated triad MRV. **THREE-IN-ONE™** "Bekker" type - that has been designed for the usage of maneuverability in overriding around of narrow ridges and anti-overturn stability on steep slopes. This MRV will be the train of two or three **vehicle-units** (VUs) propelled electromechanically, and coupled articulately with the aid of **fuzzy-logic** (FL) and **neural network** (NN) mechatronically controlled articulation **inter-unit** (ID) electromechanical couplers (coupling joints) and/ or steering mechanisms [4,6]. They permit rapid VUs couplings without external assistance and with substantial IU misalignment as well as a MRV steering without detracting from the tractive effort. Besides FL and NN, that is, **neuro-fuzzy** (NF) mechatronic control of the pitch attitude between VUs has been added for superior obstacle negotiation (crossing) capability. The DBW **four-wheel drive** (4WD) **middle-unit** (MU) can operate as single one that as like a LRV "Bekker" type, as far as its mobility permits. The added DBW **two-wheel drive** (2WD) **front-unit** (FU) and/or **rear-unit** (RU) should not impair normal operation. The two or three VUs may be coupled when the astronaut- or robotic-driver anticipates that the single DBW 4WD MU cannot handle a certain terrain or obstacle, or falling that judgment, after a DBW 4WD MUD becomes immobilized. The electromechanical actuators can position and latch the nating parts of the couplers and/or steering mechanisms. Nobody is needed outside the MRV during the coupling process.

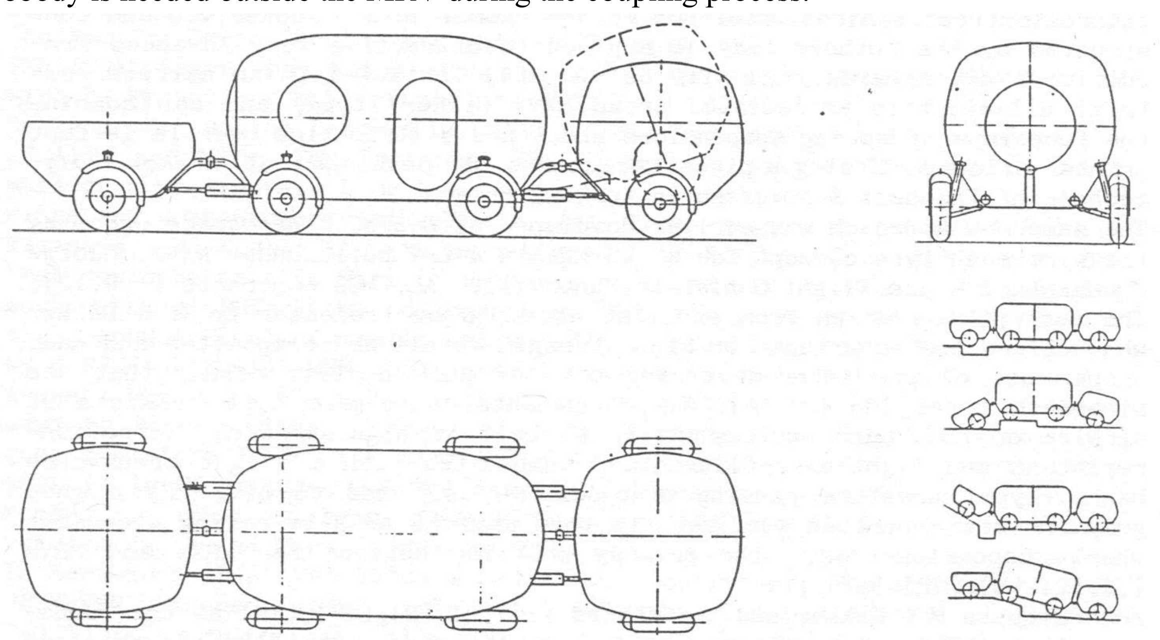

Fig. 1: All-electric pressurized articulated triad MRV **THREE-IN-ONE™** "Bekker" type

An on-board **artificial intelligence** (AI) single-chip microcomputer-based controller, that is an AI **microcontroller** (µC), has been also added to coordinate the energy source DC **chemoelectric** (C-E) **storage battery** (SB) and **fuel cell** (FC)] and DC-AC/AC-DC macro-commutator E-M/M-E wheel-hub motors/generators of the MRVs wire-mesh wheels operations and to optimize and simplify the NF control of the E-M mono-drive propulsion mechatronic control systems of both articulation joints (couplers and/or steering mechanisms) [4].

The barycenter is located at the center of the MU hull. The four steered and motorized/ generatorized wire-mesh wheels on each side of the three VUs have independent external wire-mesh wheel's suspension helical springs with variable-rate dampers (shock absorbers) without mechanical valve components using an ERF or MRF. Active control of vehicle suspensions will be realized with the fluidically suspended MRV. Linear sensors alongside the variable-rate dampers read the terrain surface. By increasing the ground clearance of the MRV, the terrain traversing capability and mobility is also enhanced. Astronauts on the Mars will be limited in the range of their explorations to objects within walking distance of their **Martian module** (MM). In not-too-distant future, the two astronauts will ride an eight-wheeled all-electric pressurized articulated triad **THREE-IN-ONE™** MRV "Bekker" type to traverse father from their landing site.

It is well-known that the bushes and geometry have strong correlations with hardness. It is elucidated the mechanism for these correlations focusing on the wire-mesh wheel's axle trajectory and its vibration characteristics. The hardness mechanism may be analyzed using ADAMS simulation.

A flexible ring the Bekker tire physical model may be used for the analysis. This means that the profile of the Mars surface acts on the tread of the Bekker tire as forced vibration by displacement. The elastic deformation of the tread is enabled by making a physical model of the Bekker tire tread in which, for example, 360 rigid bodies are linked by springs. Contact with the Mars surface may be simulated by setting a nonlinear spring between the Mars surface and the tread.

The influence of MRV speed, bush stiffness, and geometry on the wire-mesh wheel's axle separation width may be investigated.

The forced vibration by displacement (input in actual driving) that is input from the Mars surface during actual driving may be replaced by the wire-mesh wheel's axle external force. The latter acting on the wire-mesh wheel's axle is equivalent to the reactive force at the constraint point when passing over a cleat with the axle constrained.

The wire-mesh wheel's axle vibration may be indicated in terms of equation (1) using the wire-mesh wheel's axle external force and this axle impulse response, namely:

$$x(t) = \int_0^t h_{xx}(t-\tau) f_x(t) d\tau + \int_0^t h_{xz}(t-\tau) f_z(t) d\tau \qquad (1)$$

where: $h_{xx}(t)$ – impulse response (longitudinal response to wire-mesh wheel's axle longitudinal input);

$h_{xx}(t)$ – impulse response (longitudinal response to wire-mesh wheel's axle longitudinal input);

$f_z(t)$ – impulse response (longitudinal response to wire-mesh wheel's axle vertical input;

$f_x(t)$ - wire-mesh wheel's axle longitudinal input (longitudinal reaction force at the constraint point with axle constrained).

If equation (1) will be converted to a function of angular frequency, *X(_)*, it will be obtained equation (2), as it may be written below:

$$X(\omega) = H_{xx}(\omega)F_x(\omega) + H_{xz}(\omega)F_z(\omega) \qquad (2)$$

where: *H_{xx}(_)* – wire-mesh wheel's axle transfer function (longitudinal response to wire-mesh wheel's axle longitudinal input):

H_{xx}(_) – wire-mesh wheel's axle transfer function (longitudinal response to wire-mesh wheel's axle longitudinal input):

F_x(_) - angular frequency characteristics for wire-mesh wheel's axle longitudinal input;

F_x(_) - angular frequency characteristics for wire-mesh wheel's axle vertical input.

The MRV, weighing approximately *30 kN,* resembles a stripped-down dune buggy. But it will carry more than twice its mass (gravitational force with which a MRV tends towards the center of Ute Mars) in passengers, scientific instruments [3], and Martian soil samples. Electrically powered by two separate DC C-E **silver-metal hydride** (*Ag-MH*) SBs and single DC C-E **solid-oxide fuel cell** (SOFC) driving DC-AC macrocommutator E-M wheel-hub motors on each of the eight motorized wire-mesh wheels, the MRV will have a top speed of approximately *25 km/h.* During the astronauts' stay time on the Mars, it may make several sorties totaling approximately *200 km*.

The *Krakow University of Technology's Aerospace Team is* designing a prototype of the high-qualified all-electric articulated triad **THREE-IN-ONE™** MRV "Bekker" type plus related test and training equipment.

The MRV will be carried to the Mars in the cargo compartment of the descent stage of the MM. To save space, the MRV frame will be hinged, with three VUs folding together. The eight wire-mesh wheels will be folded against the chassis.

When the astronauts leave the MM for their **extravehicular mobility unit** (EMU) activities, one of them will release the **THREE-IN-ONE™** MRV "Bekker" type from the stowage compartment. Deployment will be semi-automatic. Springs will unfold the MRV and its wire-mesh wheels, and they will lock together into the deployed position. One astronaut should be able to deploy, activate, and check the MRV quickly and easily. The single 4WD MU of the MRV will measure about *4.2 m* long, slightly more than *2.2 m* wide, and have a *2.6 m* wheelbase.

OPERATING THE MANNED MARTIAN ROVING VEHICLE

The two astronauts sit side by side in the closed-frame (capsule) 4WD MU of the **THREE-IN-ONE™** MRV "Bekker" type. Between them is a **hand control joystick** (HCJ) rather than a steering wheel. The MRV can travel for-and/or backward at variable speeds.

The **astronaut-driver** (AD) sets a toggle switch to provide electrical energy to the DC macrocommutator E-M wheel-hub motors of the eight motorized wire-mesh wheels, then uses the HCJ to control movement. He or she lifts the HCJ forward to go ahead, backward for reverse, left and right for steering, and pulls straight back to apply the ring brakes. All eight motorized wire-mesh wheels turn to steer around obstacles, and the turn radius will be no more than the length of the MRV. MRV's closed-frame (capsule) will be habitable without EMU space suits. On the first trip to Martian surface, the MRV Is scheduled to be used by the MM astronauts who will land on the Red Planet's flat surface - similar to terrain found at the **VIKING 2** site on Mars. The MRV will increase both the range and the actual exploration portion of the time that the astronauts spend on the Mars surface.

MARTIAN ROVING VEHICLE CAPABILITY

The **THREE-IN-ONE™** MRV "Bekker" type can negotiate step-like obstacles *.3 m* high and cross crevasses of *0.4 m*. Wheel diameter is *0.9 m.* The fully loaded MRV, carrying a total mass of *4.5 Mg*, can climb descent slopes as steep as $\pi/9$ (20°). A parking brake can hold the MRV stationary on slopes of $\pi/6$ (30°) or less. It will have ground clearance of at least *0.4 m* on a flat surface.

The MRV will carry a Martian communications relay unit for communications with Earth when it is out of line of sight with the MM. It will relay voice and bio-medical data from the astronauts' EMU suit-contained communications, and In addition, it will relay television coverage to the Earth or Moon. This unit is provided by the ***Manned Spacecraft Center*** *(MSC),* and will be mounted after the astronauts are on-the-Martian surface. Voice, television, and telemetry will be relayed between a driving or stationary MRV and the Earth or Moon ground via the communications satellites. This new technique more than tripled the communications coverage otherwise available. The Mars is much smaller than the Earth in diameter, and the astronauts will quickly be over the horizon and out of sight of the MM. Since a magnetic compass cannot be used on the Mars, an important feature of the MRV will be a built-in navigation system that will tell the astronauts the sense of direction and distance back to the MM at all times, as well as the total distance they have traveled [5]. Reliability is obtained through simplicity in design and operation and through redundancy. For instance, there are two complete DC C-E SBs, each sufficient for powering the MRV. The DBW 4WD MU of the MRV is normally steered by both the front and rear steered and motorized/generatorized wire-mesh wheels; however, if one steering mechanism falls, it will be disconnected and the remaining steering system will do the job.

A separate DC-AC/AC-DC macrocommutator E-M/M-E wheel-hub motor/generator that has a sealed drive to prevent problems of Martian dust propels each steered and motorized/generatorized wire-mesh wheel. Even if two wheel-hub motors fail, the 4WD MU of the MRV can continue to be driven by simply decoupling the failed wheel-hub motor to free the wheel.

Designers of the MRV will be studied samples of the Mars's soil recognized by robots of the **MARINER 9**, **MARS 1-7** and **VIKING 1-2** missions, as well as the data gathered through photographs, films, and observations of the robots during the flights [10], [11], [16], [20]. The consistency and mechanical behavior of the Martian soil should not hamper the MRVs operations.

Properties of the soil have been carefully considered in designing a wheeled pressurized articulated triad MRV that will travel the Mars surface with its alien environment, reduced gravity [18], and extremes of temperature. The flexible metal or composite steered and motorized/generatorized wire-mesh wheels, made of woven wire, are rugged, light, and have good traction characteristics.

MARTIAN ROVING VEHICLE TRAINER

A special-purpose prototype of the MRV trainer, designed for operation In the stronger gravity field on Earth, will be used for mobility tests and to teach and train the astronauts how to operate the extraterrestrial manned and/or unmanned wheeled EV. It is called a **ONE-G-THREE-IN-ONE™** MRV trainer because it will operate in Earth's gravity. The EV will be very similar to MRV flight models for use on the Mars, but the trainer's motorized wire-mesh wheels' tires will be replaced by conventional type-type ones for most of its tests, which will be conducted at the *Krakow University of Technology*, Poland.

FRONT-, MIDDLE- AND REAR-UNITS
WITH THE ELECTROMECHANICAL/MECHANOELECTRICAL
STEERED AND MOTORIZED/GENERATORIZED WIRE-MESH WHEELS

A very unique type of MRV designed for enhanced mobility will be the extraterrestrial all-electric pressurized articulated triad **THREE-IN-ONE**^{TM} MRV "Bekker" type, shown in Figure 1, driven by eight electromechanical/mechanoelectrical steered and motorized/ generatorized wire-mesh wheels, which will have **front- and/or middle- and/ or rear-units** [F&M&RUs].

The F&M&RUs have wire-mesh wheel single-axles, which are powered by the AC-AC and/or DC-AC/AC-DC macrocommutator E-M/M-E wire-mesh-wheel-hub motors/generators each, and are built into the MRV s units. The purpose of this configuration is to aid the MRV In trench crossing operations. In the events that the MRV encounters a situation that requires the use of all steered and motor-ized/generatorized wire-mesh wheels, they are simply lowered by the MRV astronaut-driver. The wheels are self-driven steered and motor-ized/generatorized wire-mesh wheels. When the wheels are no longer needed, they are elevated back up into the raised position. Trench crossing for a wire-mesh wheeled MRV is normally limited but the MRV s wheel size, wheelbase and the barycenter. However, utilizing these MU wheels that are the electromech-anical/mechanoelectrical steered and motor-ized/generatorized wire-mesh wheels will reduce the problem of negotiating trenches.

Electrical energy for the AC-AC and/or DC-AC macrocommutator wheel-hub motors will be provided by two DC C-E SBs and single DC C-E SOFC, situated in the MU, as well as by a space nuclear power supply hyposphere with the **radioactive-isotope thermo-electrical generator** (RTG) for space exploration, situated in the RU.

The E-M/M-E DBW AWD propulsion and BBW AWB dispulsion mechatronic control systems of the extraterrestrial all-electric pressurized articulated triad MRVs **front- and/or rear-units** (F&RUs) will be completely independent of the MU E-M VAP mechatronic control system. When the AC-AC and/or DC-AC macrocommutator E-M wheel-hub motors will be engaged, the MRV can act as an *8 x 8* (triple-unit) at travel speeds up to *25 km/h*.

The "**THREE-IN-ONE**" with the electromechanically powered F&M&RUs has the advantage of a light extraterrestrial all-terrain carrier, but when re-quired, can be used as a small tractor MU for heavy F&RUs. Otherwise, no additional MU mass (dead mass) will be required to provide adequate tractive effort in the powered F&RU modes.

Additionally, in adverse terrain, the powered F&RUs have the capabilities to pull/push the small tractor MU. The blocky shape, aggressive stance, and highly functional DBW AWD propulsion control system are all part of the style of one of the most distinctive MRV designs on the market. The MU-body construction enhances interior room and lowers the barycenter.

The alterations ought to be intended to improve on-slope precision, where MRVs spend most of their time, without compromising the off-slope capabilities.

AC-AC AND/OR DC-AC/AC-DC MACROCOMMUTATOR RELUCTANCE & MAGNETOELECTRIC WHEEL-HUB MOTORS/GENERATORS

Over the last twenty years the design of **magneto-mechano-dynamical** (MMD) electrical machines has been increasingly dependent upon their analysis by **finite-element-method** (FEM) techniques. Continuing advances in affordable computer sciences have enabled comprehensive studies to be performed with great refinement. Interesting results can be demonstrated by those techniques for an AC-AC and/or a DC-AC/AC-DC macrocommutator E-M/M-E motor/generator – increasingly used where torque and speed control are used - linking the AC-AC and/or DC-AC/AC-DC single-chip **application specific integrated matrixer** (ASIM) macrocommutator switching with the motor's rotor rotation. Results obtained are such that it is possible to realize the motor's rotor torque variation resulting from the non-sinusoidal current supplied by the single-chip ASIM macrocommutator, and even the effects of individual rotor bars moving past stator teeth that enable generated harmonics to be calculated. Such DBW AWD propulsion mechatronic control systems are typical of modern automotive very advanced propulsion (VAP) technology where space and cost requirements demand that the high-power switching devices, that are the high-power single-chip ASIM macrocommutators, usually consist of high-power **integrated matrixers** (IMs) with '*conti-nuous*' **triggered & quenched** (T&Q) bipolar electrical valves [for Instance, '*continuous*' bi-polar **gate turn-off** (GTO) and **zero turn-off (**ZTO) thyristors or MOSFETs], are operated at the edge of their performance capabilities. Under these circum-stances a detailed under-standing of the ASIM macrocommutator's electrical-valve switching characteristics is essential and major studies have been made in this area. Complex experiments have been performed on ASIM macrocommutator's electrical-valve triggering (turn-on) and quenching (turn-off) behavior, producing valuable insights for design purposes.

High-power ASIMs have an essential role as AC-AC and/or DC-AC/AC-DC single-chip ASIM macrocommutators in heavy-duty electrical applications such as VAP and **very advanced electroenergetics** (VAE) systems. This means that, as improvements in the performance of these systems are being sought, so there is an eyed-increasing trend to extend the electrical specifications of high-power ASIMs. This requires improvements, not only to the design and manufacture of the ASIMs but also to the technology for cooling the IM during operation, because the efficiency of heat removal is a major constraint on electrical performance.

Macroelectronics development has improved ASIM macrocommutator performance by the use of energy recovery ASIMs that both increase) conversion efficiency and reduce the present heavy cooling requirements. A prototype ASIM macrocommutator, including these techniques, has provided the basis for modern automotive designs.

Equally important for high-power ASIM macrocommutators have been fiber-optic-based telemetry and control systems for high-power '*continuous*' T&Q bipolar electrical-valve switching. Electrical insulation materials and their processing are critical for all VAE spheres. Vacuum techniques to produce void-free, and thus discharge-free, materials led to composite clamping bands for high-power ASIM macrocommutator's ASIMs and to a composite insulator for them using glass-epoxy pressure plates, with **ethylene propylene diene monomer** (EPDM) sheds for Increased surface creepage resistance, to contain SF - Insulated contacting elements. Similar technologies have been applied to brushing for electrical machines, and to high-performance encapsulations for the single-chip ASIM macrocommutators as well as the topmost compact transformers.

The recent advent of **neodymium-iron-boron** (*Nd-Fe-B*) magnet-pole materials has created a new set of constraints in the design of the electromechanical/mechamoelectrical steered and motorized/generatorized wire-mesh wheels with the AC-AC and/or DC-AC/AC-DC macrocommutator E-M/M-E wheel-hub motors/ generators **MAGNET-ROTA™**, conceived and constructed by the author, which may be applied to automotive VAP systems for extraterrestrial all-electric pressurized articulated triad MRVs. Their remanence, of the order of *1.1 T*, makes it practicable to mount the magnet poles ad-jacent to the airgap, where the peak magnetic flux density is likely to be of the order of *0.8 T.* That is, it is no longer necessary to employ the magnetic flux con-centrating techniques of burled magnet-pole stators or rotors.

At present, the most accessible magnet poles are cast in a block and sawn with a pre-ferred sense of magnetization direction. This encourages the design and construction of axial magnetic flux or '*pancake*' MMD electrical machines, whose iron cores are in the shape of a ring and whose airgaps are flat. A single ring-shaped inner-stator, single ring-shaped outer-rotor design sets up a strong attraction force that requires that the bearings support end thrust. The twin ring-shaped inner-stator, single ring-shaped outer-rotor design balances the attraction forces and eliminates the end thrust. This configuration has been used for AC-AC and/or DC-AC macrocommutator E-M/M-E wheel-hub motors/generators **MAGNET-ROTA™**.

Many others planetary gearless E-M/M-E steered and motorized/generatorized wire-mesh wheels with the AC-AC and/or DC-AC/AC-DC macrocommutator reluctance & magneto-electric [unwound **magnetized-soft-iron** (MSI) single ring-shaped outer rotor and wound & **interior-permanent-magnet** (IPM) twin ring-shaped inner stator] wheel-hub motors/ generators have also conceived by the author. Whether or not all of these **magneto-mechano-dynamlcal** (MMD) electrical machines qualify as E-M/M-E motors/generators tend to be a controversial question. Whatever their form, the common operational mode is that a discrete quantum of angular rotation occurs in response to a pulse. For continual rotation to take place, a properly coded pulse train must be applied so that there is a sequential '*stepping*' motion of the single ring-shaped outer-rotor. In essence, the pulse coding is such that a rotating field is produced. One of the salient features of these MMD electrical machines is the ability to repeat positional data. No feedback loop is required for such performance.

A principle layout of a particularly interesting planetary gearless E-M/M-E steered and motorized/generatorized wire-mesh wheel with the MMD electrical machines of this kind is one with the AC-AC and/or DC-AC/AC-DC macrocommutator reluctance & magnetoelectric (unwound MSI single ring-shape outer-rotor and wound & IPM twin ring-shaped inner stator) E-M/M-E wheel-hub motor/generator **MAGNET-ROTA™** RX-III shown in Figure 2. It is evident that there no windings on the MSI single ring-shaped outer-rotor, no slip rings, and no mechanocommutator with the sliding-copper-segments and their carbon brushes. Not evident is the nature of the twin ring-shaped inner-stator poly-phase (three- or five-phase) windings. If the twin ring-shaped inner-stator will be a six-pole, three- or five phase structure with a large number of '*teeth*', then the single ring-shaped outer-rotor will be also toothed and will be magnetized so that a south pole occupies one-half of the periphery while a north pole occupies the other half. Although the twin ring-shaped inner-stator has only six poles and the single ring-shaped outer-rotor has only three poles, the presence of '*teeth*' on both members affords a large number of opportunities for positional '*lock-up*' of the single ring-shaped outer-rotor. Poles N1, S4, N7 and SIO form the first phase; poles N2, S5, N8 and S11 form the second phase; poles N3, S6, N9 and S12 form the third phase.

The AC-AC and/or DC-AC/AC-DC macrocommutator reluctance & magnetoelectric wheel-hub motor/generator with different pole numbers on the unwound MSI single ring-shaped outer-rotor and the wound & IPM ring-shaped inner-stator can provide traction If the stator poly-phase winding phase-coils are sequentially energized. Here the unwound MSI single ring-shaped outer-rotor is made to '*chase'* sequentially switched wound & IPM twin ring-shaped inner-stator's poles. As soon as magnetic alignment occurs, the attracting pole is de-energized. A variation of this basic scheme employs Hall-effect elements to directly sense the position of ether the single ring-shaped outer-rotor itself, or a suitably magnetized ring on the shaft.

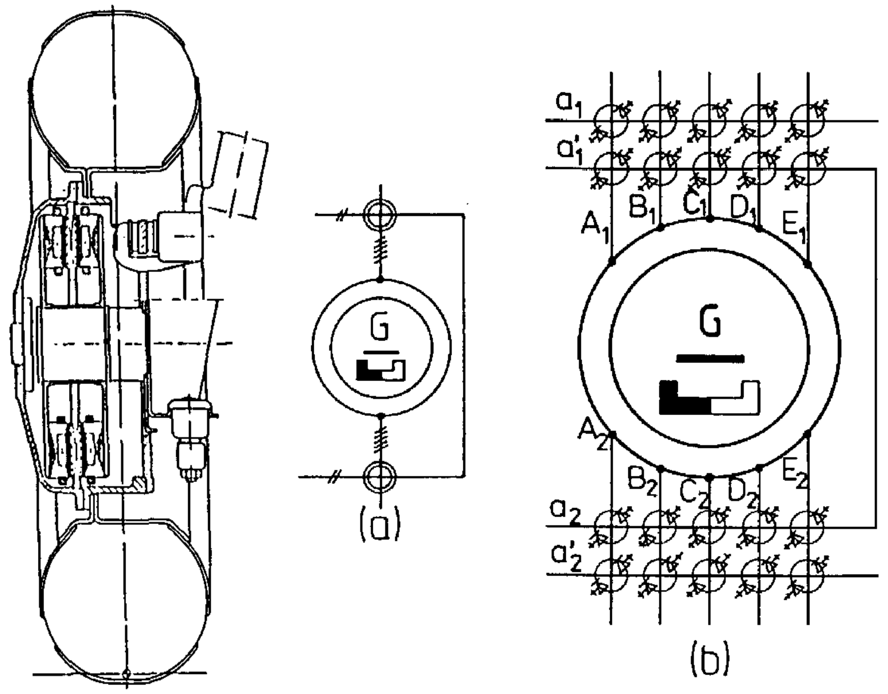

Fig. 2: Planetary gearless E-M/M-E steered and motorized/generatorized wire-mesh wheel with the AC-AC and/or DC-AC/AC-DC macrocommutator reluctance & magnetoelectric E-M/M-E wheel-hub motor/generator MAGNET-ROTA™ RX-III

The AC-AC and/or DC-AC/AC-DC macrocommutator reluctance & magnetoelectric wheel-hub motor/generator adopts the '*IMP bias*' method, the IPM made *Nd-Fe-B* rare-earth metal alloy is located at the center of the twin ring-shaped inner-stator cores. Both the IPM and the poly-phase armature winding phase-coils on the twin ring-shaped inner-stator create the magnetic field and the output torque is proportional to the square of the sum of both fields. The torque is proportional to the square of the sum of the magnetic flux of the IPM inductor and the magnetic flux of the twin ring-shaped inner-stator's poly-phase armature windings. Significantly, the AC-AC and/or DC-AC/AC-DC macrocommutator E-M/M-E wheel-hub motor/generator is designed both as reluctance and as a magnetoelectric wheel-hub motor. It is, indeed, both or these.

Moreover, it is described as an IPM inductor (unwound MSI single ring-shaped outer-rotor and/or wound & IPM twin ring-shaped inner-stator) E-M/M-E wheel-hub motor/generator.

ON THE MARS

Due to the time limitation of the EMU's life support systems in the backpacks, and potential fatigue of the astronauts, use of the **THREE-IN-ONE™** MRV "Bekker" type will be divided into several sorties during their few-day stay on the Mars.

For safety reasons, the astronauts will remain within *5 km* of the landing site. From this distance they can walk back to the MM should their MRV break down. While it may appear at first glance that a *5 km* exploration radius is very restrictive within this area for the investigations. For instance, *NASA* and *ESA* are modifying the spacecrafts, the EMU space suits worn by the astronauts, and EMU's life support systems to permit them to remain on the Martian surface up to few days during the not-too-distant future missions. The MM will be able to land more mass on the Mars. Part of this extra mass-carrying capacity will be used to transport, for example, the MRV. It will have a minimum operational lifetime of *78 h* during the Martial day. *NASA* and its contractors have been studying many different types of LRVs and MRVs since the early 1960's.

Some of the very advanced concepts would be capable of missions ranging up to fortnight in the manned mode, and up to one year operation unmanned, driven by telerobotic-drivers or remotely (from Earth or Moon) and ranging more than *500 km* over the Mars surface.

SUMMARY, CONCLUSIONS AND SPECULATIONS

One of the greatest scientists in the history of '*terramechanics*', the never—enough-to-be-regretted Pole *Professor Dr **M G Bekker*** '*Father of Terraln-Vehicle Systems*', best known for the invention of a steel transparent-type track for tracked vehicles and pioneering construction of a wire-mesh wheel and other members of the LRV for *NASA* foresaw a break-through for the all-electric-wheel '*single-shaft*' type VAP systems in smart wire-mesh wheeled extremely-high-mobility LRVs and MRVs for aerospace use 1990-2020. The extremely-high-mobility extraterrestrial all-electric pressurized articulated triad **THREE-IN-ONE™** MRV "Bekker" type, shown In Figure 1, will have a yaw type of **very advanced diversion** (VAD) system, including steering system which incorporate E-M motorized yaw actuators with the linear tubular DC-AC macrocommutator E-M actuator-motors mounted between the three **vehicle-units** (VUs).

When the MRVs HCJ will be lifted the yaw actuators will be activated and push/pull the **front- and/or rear-units** (F&RUs) with respect to the **middle-unit** (MU) until the desired turn will be made. This VAD system will be proven to be a relatively effective mobility feature because there will be no power loss in braking the steered, motorized and/or generatorized wire-mesh wheels for steer-ing as in a conventional steered LRVs.

When steering the "**THREE-IN-ONE**", all E-M/M-E steered and motorized/generatorized wire-mesh wheels will be still-powered, providing smooth and continual power to all steered and motorized/generatorized wire-mesh wheels that will allow the MRV to achieve maximum tractive effort.

One of the primary factors that determine the degree of mobility a wire-mesh wheeled "**THREE-IN-ONE**" will have in adverse terrain is the amount of wire-mesh wheel's endless belt contact area that is exposed to the terrain. Assuming that all else is - equal, an *8 _ 8* "**THREE-IN-ONE**" that is capable of having all eight steered and motorized/generatorized wire-mesh wheels in contact with the ground in a given terrain will be more mobile than an *8 _ 8* "**THREE-IN-ONE**" that has only seven steered motorized/generatorized wire-mesh wheels in contact with the ground. A feature that the author wills has occasionally incorporated on a wire-mesh wheeled “**THREE-IN-ONE**” is multi-axle steering. The primary advantage of this feature is the reduced turning diameter (radius) that an MRV must travel. When an MRV is negotiating terrain where extremely tight cornering or when other close turning maneuvers are necessary, multi-axle steering can be beneficial to the handling and overall MRV mobility. The "**THREE-IN-ONE**" *8 _ 8* (triple-unit) incorporates full time front-, middle- and/or rear-axle steering.

NF make them possible to program the MRV-motion control’s SBW AWS diversion, ABW AWA suspension, DBW AWD propulsion and BBW AWB dispulsion mechatronic controls of macro- and/or microelectronic devices so that they make the same kind of approximations as well skilled and experienced AD would make. The concept is only now beginning to gain acceptance in the automotive industry, where initial reaction was, at best, skeptical. But in the other industries NF have enjoyed enthusiastic support.

Standard MRV-motion control theory would use a set of differential equations to model the characteristics of the driver-vehicle and terrain-vehicle dynamics, and then solve the equations to MRV-motion control using feedforward- and/or feedback-processes. But the MRV-motion control can be used when there is no good mathematical model of the MRV-motion control system. It can also work without a complete rule set, whereas a micro-controller using standard logic must have rules to cover every possibility.

Astronaut-vehicle and terrain-vehicle **real-time** (RT) expert system are much more practical and likely to me manufactured in the nearest future. AD involvement may not only be at high hierarchical levels of abstraction – some low hierarchical level missions are very difficult for **artificial intelligence** (AI).

An AD perceives terrain conditions by visual sensation and senses, for instance, steered, motorized and/or generatorized road wheel slippage by bodily sensation. By comparison with past experience, the AD decides on a given amount of command MI signals to be applied, that is, HCJ’s position. While NF controls are considered to be applicable to qualitative approaches, it can replace perception and sense.

Automotive scientists and engineers are very good at image interpretation though route guidance planning (deciding which way to drive) is relatively easy to computerize. It is possible to contemplate the capabilities of the AD being utilized by the AI.

The author uses NF as the basis for fuzzy linguistic MRV-motion control's SBW AWS diversion, ABW AWA suspension, DBW AWD propulsion and BBW AWB dispulsion mechatronic control systems that gives civilian and/or military wheeled and tracked automotive vehicles human-like reasoning capabilities.

In the MRV of the future, MRV-motion control's SBW AWS diversion, ABW AWA suspension, DBW AWD propulsion and BBW AWB dispulsion mechatronic control systems might not only do much of the work, they might also monitor themselves, respond flexibility to changing demands and emergencies, and have the intelligence to keep SBW AWS diversion, ABW AWA suspension, DBW AWD propulsion and BBW AWB dispulsion mechatronic control systems operating smoothly and efficiently. Such is the hope of the author at the *Krakow University of Technology* who is working towards this goal using several AI techniques.

It is also hoped that this paper will encourage automotive scientists, engineers, and technicians to make closer study of all-electric automotive VAS, VAP and VAD systems' problems and will stimulate further theoretical and experimental R&D work in this area of EV technology.

In 1986, the *National Commission on Space* (USA) issued a report proposing a step-by-step effort for America's future space activities. The *Commission* wants the United States of America to open inner solar system for scientific inquiry, exploration, and enterprise leading to human outposts on the Moon by 2005 and on the Mars by 2020 [14].

In view of the above-mentioned positive aspects aerospace institutions such as *NASA* and *ESA* are taking increasing advantage of this type of extraterrestrial all-electric pressurized articulated triad **THREE-IN-ONE**$^{\mathbf{TM}}$ MRVs.

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