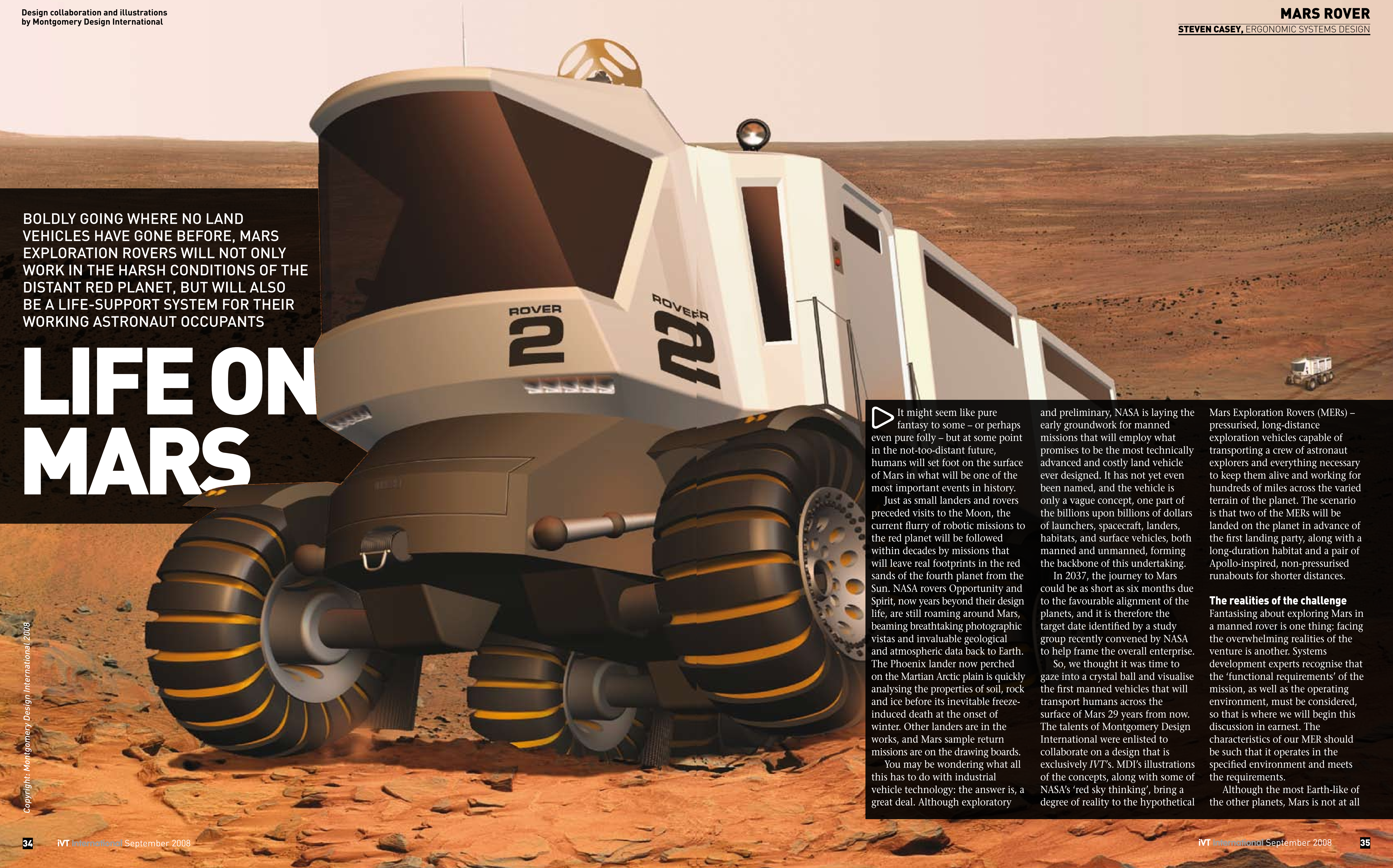
STEVEN CASEY, ERGONOMIC SYSTEMS DESIGN



BOLDLY GOING WHERE NO LAND VEHICLES HAVE GONE BEFORE, MARS EXPLORATION ROVERS WILL NOT ONLY WORK IN THE HARSH CONDITIONS OF THE DISTANT RED PLANET, BUT WILL ALSO BE A LIFE-SUPPORT SYSTEM FOR THEIR WORKING ASTRONAUT OCCUPANTS

LIFE ON MARS

It might seem like pure fantasy to some – or perhaps even pure folly – but at some point in the not-too-distant future, humans will set foot on the surface of Mars in what will be one of the most important events in history.

Just as small landers and rovers preceded visits to the Moon, the current flurry of robotic missions to the red planet will be followed within decades by missions that will leave real footprints in the red sands of the fourth planet from the Sun. NASA rovers Opportunity and Spirit, now years beyond their design life, are still roaming around Mars, beaming breathtaking photographic vistas and invaluable geological and atmospheric data back to Earth. The Phoenix lander now perched on the Martian Arctic plain is quickly analysing the properties of soil, rock and ice before its inevitable freeze-induced death at the onset of winter. Other landers are in the works, and Mars sample return missions are on the drawing boards.

You may be wondering what all this has to do with industrial vehicle technology: the answer is, a great deal. Although exploratory and preliminary, NASA is laying the early groundwork for manned missions that will employ what promises to be the most technically advanced and costly land vehicle ever designed. It has not yet even been named, and the vehicle is only a vague concept, one part of the billions upon billions of dollars of launchers, spacecraft, landers, habitats, and surface vehicles, both manned and unmanned, forming the backbone of this undertaking.

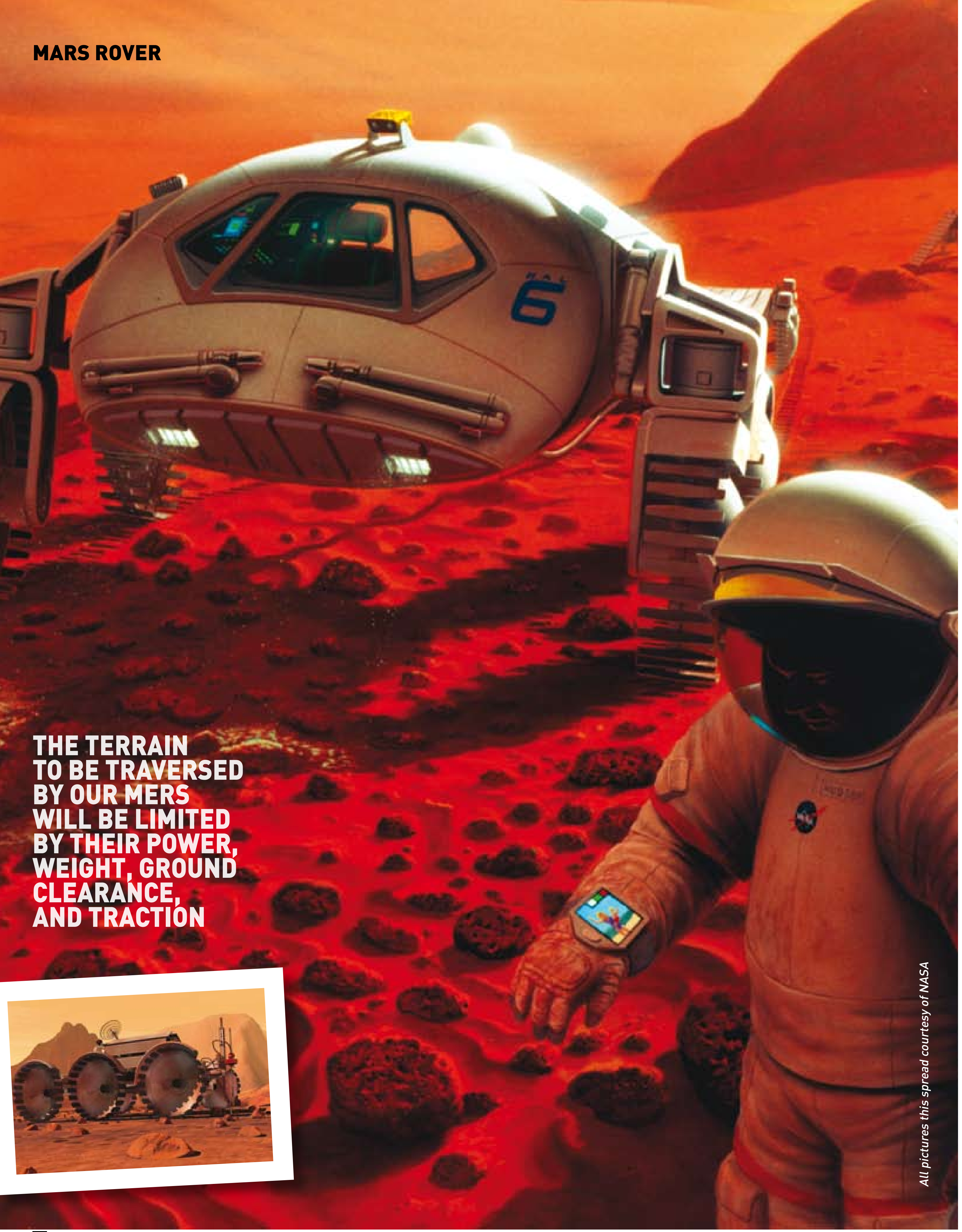
In 2037, the journey to Mars could be as short as six months due to the favourable alignment of the planets, and it is therefore the target date identified by a study group recently convened by NASA to help frame the overall enterprise.

So, we thought it was time to gaze into a crystal ball and visualise the first manned vehicles that will transport humans across the surface of Mars 29 years from now. The talents of Montgomery Design International were enlisted to collaborate on a design that is exclusively *IVT*'s. MDI's illustrations of the concepts, along with some of NASA's 'red sky thinking', bring a degree of reality to the hypothetical Mars Exploration Rovers (MERs) – pressurised, long-distance exploration vehicles capable of transporting a crew of astronaut explorers and everything necessary to keep them alive and working for hundreds of miles across the varied terrain of the planet. The scenario is that two of the MERs will be landed on the planet in advance of the first landing party, along with a long-duration habitat and a pair of Apollo-inspired, non-pressurised runabouts for shorter distances.

The realities of the challenge

Fantasising about exploring Mars in a manned rover is one thing: facing the overwhelming realities of the venture is another. Systems development experts recognise that the 'functional requirements' of the mission, as well as the operating environment, must be considered, so that is where we will begin this discussion in earnest. The characteristics of our MER should be such that it operates in the specified environment and meets the requirements.

Although the most Earth-like of the other planets, Mars is not at all



THE TERRAIN TO BE TRAVERSED BY OUR MERS WILL BE LIMITED BY THEIR POWER, WEIGHT, GROUND CLEARANCE, AND TRACTION

All pictures this spread courtesy of NASA

'user friendly'. Unlike Earth, which has a healthy magnetic field, what is left of the Martian atmosphere is slowly being stripped away by the solar wind. The situation is made worse by its lower density (71% of Earth's), its smaller overall size (53% of Earth's diameter), and its lower gravity (38% that of Earth).

The major consequence of all this is an atmosphere with around 1% the pressure of Earth's at sea level. In fact, atmospheric pressure at the lower altitudes equals atmospheric pressure on Earth at an altitude of about 35km. Mars' atmosphere is relatively high and thin, so pressure suits or a pressurised atmosphere are required for human survival at all times, which has a profound impact on not only the structural integrity of habitats and environmental systems, but on interior space.

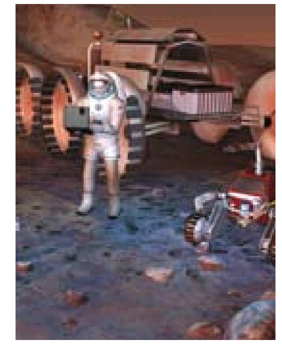
The thin Martian atmosphere is composed of 95.32% CO_2, 2.7% nitrogen, 1.6% argon, 0.13% oxygen, 0.08% carbon monoxide, as well as trace amounts of water, nitrogen oxide, neon, hydrogen-deuterium-oxygen, xenon and krypton. An IC engine is therefore impractical, and contained environmental systems would have to be largely regenerative. All critical components will have to be fail-safe or have a back-up.

Typical daytime temperatures on Mars range from -89° to -31°C, and average -63°C near the equator. The poles fall to a low of -140°C, but, perhaps surprisingly, can inch up to a balmy 20°C in the summer. Overall, it is a very cold place, and a lot of energy will be required to keep astronaut habitats and pressurised rovers warm for human habitation.

Mars is also very dusty and windy, with wind speeds up to 67mph, and several times that at the poles when they are warmed by sunlight at the end of winter. Dust is everywhere, and the common small dust particle size of 1.5μm diameter will create challenges for mechanical equipment as well as people.

The terrain to be traversed by our MERs will, of course, be limited by their power, weight, ground clearance, and traction. In terms of what Mars has to offer for 'off-roading', the variability is great. There are the southern highlands with impact craters to study, as well as the flat northern plains that we now know were once covered with water. The tallest mountain in the solar system, Mount Olympus, reaches 26km into the sky – three times the height of Mount Everest.

Unlike the six Apollo lunar landings where each craft landed and returned from different locations, initial manned missions to Mars will have a central start and end point. Our MERs, therefore, will do the brunt of the work in transporting astronauts and equipment over variable terrain out from this single landing and habitat base. The initial crew will play it safe and venture out in relatively flat terrain, and subsequent crews will head out to the mountains and geologically important points on adventurous trips that will be many hundreds of miles in length and will span many weeks.



The MERs will also face problems related to radiation – both solar and ionising. The amount of solar radiation falling on Mars' surface is roughly half that which falls on Earth. This necessitates much larger solar collection arrays for an equivalent amount of energy capture and electrical generating capacity. Additionally, there is the issue of Martian dust, which has the nasty habit of settling on robotic landers and substantially reducing the electrical output of their solar arrays.

Solar UV radiation reaching the surface of Mars, on the other hand, is extremely high and will require astronauts and their environments to be thoroughly shielded. And without the protective cover of the magnetosphere as on Earth, the level of ionising radiation reaching the surface can be of serious concern over the long term. Certainly, radiation shielding from both cosmic rays as well as x-ray flares will be required on our MERs.

IC ENGINES WILL BE IMPRACTICAL ... AND ALL COMPONENTS WILL HAVE TO BE FAIL-SAFE

Roving out and about

It is also important to consider which activities will be performed with each of the two Rovers. Current planning calls for three crews of six astronauts, each visiting Mars in succession, with each crew exploring for 16-20 months. The pre-positioned habitat, two pressurised Rovers, two unpressurised runabouts, and most other support equipment will have been previously landed, unmanned, at the base site. Beginning with small excursions and building up to treks lasting days and then weeks, the two MERs will, individually or as a pair, travel along predetermined routes on expeditions to conduct detailed mapping and topographic studies, geology and soil research, and atmospheric analyses. They will also be used to search for evidence of ancient life and clues to the geological history of the planet.

Astronauts will live, eat, sleep, work, perform ablutions, and maybe even exercise within the confines of the MER. In a sense, each rover will become a mobile habitat much like the home base, and must therefore support almost the same human activities as the main stationary base station. The confines of the interior will be tight to say the least, but a typical crew of two to four will have ample room – about the same amount as in a small motor home or below deck on a 10m yacht back on Earth. The air lock will serve as the obvious portal for extravehicular activities (EVAs), but will also provide a buffer and cleaning station for the pervasive Martian dust.

Each rover will be manned by two to four astronauts on most occasions, but be capable of sustaining and transporting as many as six in an emergency (just as Apollo XIII's two-person lunar lander sustained the three-man crew after their ill-fated trip to the Moon). There will also be a back-up or recovery plan in place in the event of an MER breakdown. If short distances are involved, MER crew recovery might be made with the unpressurised runabouts. If long distances are involved, the second MER will serve

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MAIN IMAGE: **MER using its retrieval arms to collect meteorite samples**

INSET: **Rover 1 still working at sunset with a crew member getting in one more ground-penetrating radar sounding before heading to his bunk for the night**

as the lifeboat. (Apollo XVII astronauts were unable to stray very far from their landing craft. Although they drove a total of 17 miles on the Moon during four EVAs, they were never so far away from their safe haven that they could not walk back, given their supply of air, if their lunar rover broke down.)

The mission will make extensive use of robotic rovers for mapping, sample collection, and general 'remote' exploration. These robotic rovers would be serviced by crews transported in MERs, and controlled from Earth, the Mars base station, or by astronauts within the MERs – the latter option will be far less problematic than controlling them from Earth due to the long distances and communication time delays between the two planets. Hence, there will need to be a remote workstation within the MER as well as all equipment for servicing the robotic rovers.

Given the likely problems with Mars dust, wind, radiation, and limited atmosphere, as many activities as possible will be performed from within the MER rather than by space-suited astronauts, who must enter the air lock and work outside in a suited environment that is, 'one failure away from certain death', as a NASA mission controller once said.

Like deep sea submersibles, the MER will have remote manipulator arms and tools, all controlled by an astronaut working comfortably within. These will be able to dig, hammer and drill, but also deliver soil, ice, and rock samples into a receiving drawer for transfer inside the MER. They will also be capable of carrying a drilling attachment for obtaining core samples down to 30m. The sedimentary history of various regions will be mapped and studied, to provide a picture of the planet's past. Like many of the functions and capabilities of the MERs, drilling will require a great amount of power.

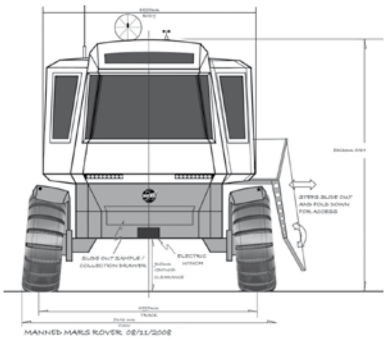
Rover design details

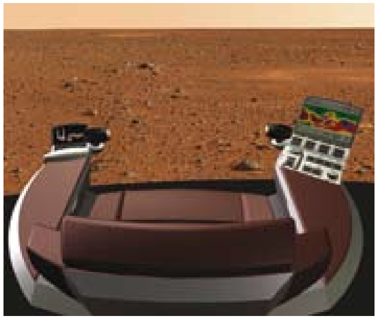
Most serious Mars expedition study groups have concluded that the demand for continuous, reliable electric power will require a nuclear power plant at the habitat as well as on pressurised rovers, and we concur with this assessment. Electric solar cells will not provide sufficient power given the available space and weight, and fuel cells will require the transport of large amounts of liquid hydrogen across interplanetary space. Pound for pound, vastly more energy can be obtained from a compact radioisotope thermoelectric generator than from any other source and, accordingly, our MER contains a modular Dynamic Isotope Power System due to its low mass and much lower radiator size than the photovoltaic array area of a solar panel.

Our shielded powerplant, located between the rear frame rails of the rover chassis, is driven by the 238Pu Plutonium isotope, and with a half-life of 88 years, it will power each rover for the six- to 10-year duration of our three landing parties. Its power output is 10kWe continuous. Each rover's powerplant will also serve as a back-up to the other rover, as well as to the habitat itself. Mindful of the need to be politically correct, we have also equipped each MER with a solar cell array to generate a low-level emergency current should the Dynamic Isotope Power System fail; a highly unlikely eventuality given their simplicity and historical use in deep-space spacecraft.

Heat from the Dynamic Isotope Power System will power a fully enclosed electric generator. Batteries will provide electricity storage and a back-up buffer, but will also be fed directly by the roof-mounted solar array. Electricity will power all environmental systems, electronics, lighting, mechanical, propulsion and steering systems.

Each of the MER's six wheels is independently powered for redundancy, and independently





If the cab fits...

CNH Power Components believes that the requirement for a NASA Martian Rover's cab would not be dissimilar to the cab installed on the Space Sprayer featured on the company's current advert (see back cover). Its FR cab is essentially designed to provide a modular operator platform, so some modification would be necessary for use in a space environment.

Because the Space Sprayer would not have to experience the stresses of re-entry, the original frame could be retained. The air-con system would be linked through a closed circuit re-breather system, with air being recycled and fresh air constantly synthesised, making up oxygen fed from the storage tanks in the hull (an oxygen tapping would allow the charging of portable units for work outside the craft).

Internally, apart from improved sealing, the cab would not change. Standard trim could be used (although the New Holland logos would be replaced with those of the OEM/space agency) and as the control and instrumentation of the cab are CANbus-compatible, everything in the vehicle system would integrate beautifully. The steering column would be replaced with a conventional aerospace control column, the base of which would fit to the flange for the existing column.

The potential pressure differences would require the replacement of all glass with a 75mm-thick glass/carbon mat-reinforced sandwich in a steel frame and locked in place with hydraulic closers and manual interlocks. Extensive cold temperature testing will confirm that the glass would not delaminate under space conditions.

Heating could be provided by a reverse-cycle heat pump deep in the impulse generators of the main impulse drives, with any waste from the cab macerated and burned in the combustion chamber of the craft's positioning thrusters.

Further details from: www.powercomponents.cnh.com

suspended, while the front and rear wheels are steerable for enhanced manoeuvrability and traction. The flexible tread bands of the 'tyres' are a nano-carbon composite with a Solimide foam core – lightweight, but exceptionally strong. The 5° wheel and tyre camber is set to improve handling and tracking in sandy soil and on side slopes. It will also help to prevent rollovers on sloping surfaces by moving the theoretical pivot outwards and decreasing the moment of force. As the tyres are custom-made, the tread is angled at the same 5° to prevent edge wear and provide better traction.

With a gravitational field only about 40% that of Earth's, Earth-strength structures and materials are not required. However, the vehicle must be heavy and strong enough to withstand the windstorms and the varied terrain it will encounter.

Overall, construction materials are exceptionally varied, and are based on the functions of each component. Strength, lightness, and reliability in the harsh environment are of paramount importance, but repairability of key components is also of great importance.

The walls of the front cab, as well as the habitat and lab modules, are made of ceramic-matrix composites, originally developed for the Space Shuttle and capable of withstanding freezing as well as temperatures well in excess of the melting point of metal alloys. Most importantly, and in contrast to the highly difficult repairs that would be required if our pressurised vessels were made of metal and were damaged by falling rocks or even punctured, the CMC walls can be repaired with ceramic fabrics impregnated with 'partially cured polymers and ceramic particles'. These repair patches were originally developed for use by space-walking astronauts making repairs to leading edges of the Space Shuttle. They are simple, extremely strong, and require few tools. Polymer patches are heated with a hand tool to a curing temperature, and become as strong as the original CMC material.

An additional benefit of using CMCs to construct pressure vessel walls is that they have low

TOP: **The spacious cab combines comfortable operation with superb visibility**

MIDDLE: **Rover 2 with the service module installed and the rear mounted crane retrieving an unmanned Rover headed for repairs**

BOTTOM LEFT: **Part of the original layout for MDI's manned Rover project, showing its 5m width**

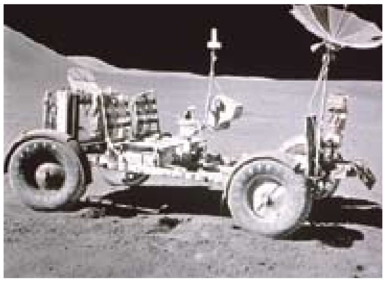
BOTTOM RIGHT: **Convenient joystick controls for operating front attachments (all pictures copyright MDI 2008)**

Improving on a legend

To consider technology for a new planetary rover requires knowledge of the last moon buggy, the famous 450 lb (75 Moon lb) 1971 Lunar Rover (LR). With a payload of 167 Moon lb, the 1971 LR was a great success. The astronauts loved it, it worked flawlessly, and astronaut Eugene Cernan dubbed it a phenomenal success without which our knowledge of the moon would be extremely limited.

Standard equipment on the 1971 LR consisted of:

- An all-aluminium frame, folding at three places;
- Four-wheel independent electric drives, with 80:1 harmonic reduction, and 0.1hp at each wheel;
- Independently operated wheel motors – the front motors could be decoupled from the rear;
- Front and rear wheels turning in opposite directions, increasing manoeuvrability;
- Spun aluminium wheels and tyres, titanium interlocking strands and bump stops to prevent wheel collapse;
- Power derived from two 36V silver-zinc potassium hydroxide non-rechargeable 121Ah batteries;
- Aluminium seat frames and webbing for upholstery – and all at a suggested retail price of US$10,000,000 from Boeing.



The classic 1971 lunar rover was limited by poor ground clearance and low battery life

The only drawback was the personal life-support system that each astronaut carried. The three vehicles were used for a total of only 10 hours and 54 minutes, covering only 90.4km over varying terrain, manoeuvring to avoid rocks that could have easily been cleared by an Earth vehicle.

Issues from the last rover that would have to be addressed are ground clearance, the limitation of the personal life-support system, weight and battery life. A new design would therefore have to include drive wheels (or possibly tracks) mounted on drive stalks that would also form part of the suspension. Because of the Moon's lower pull of gravity, carbon fibre could be used, with an 'integral to the drive stalk' small gearbox and motor combination. The design cue for this suspension can be taken from a Baja buggy – rugged and dependable, extremely lightweight, but with more than ample suspension travel.

A pressurised cockpit space would be required to allow the astronauts to operate inside just as if they were on Earth, only using their PLSS packs when they were outside the vehicle. Pressurising the cockpit would mean that the vehicle for the first time would have a skin, which would likely be carbon fibre. To maintain cab pressurisation integrity, an internal entry portal could be established to help with the transition of the astronauts from the rover to the planet's surface.

The prime mover would have to be electric power: and as a designer of drive systems for electrically powered vehicles, Comer Industries would embrace such a complex design. High-tech materials, coatings and sensors would have to be used in any lunar rover drive system design to ensure the astronauts' safe return.

Although the first LR had sensors, the Mars Rover will have sensors that are sophisticated to the point that NASA will find out everything it ever wanted. Fasteners will have to be pre-engineered for the application, and according to Vimi Engineered Fasteners, the material, coatings and design would have to be cutting-edge to withstand weight, strength and the fine Martian dust.

Battery life and design has been extended so much over the last 37 years that more than double the amp hours will be available at a fraction of the weight of the original batteries, leaving more room for payload.

Four astronauts would be carried, two facing forwards and two rear facing. A window at the rear would enable use of a robotic arm to pick up samples, and deposit them into a detachable container.

Bruce Kepley, Comer Industries

conductivity and high insulation values. Unlike the aluminium walls of an aircraft flying at high altitude at -50°C in the Earth's atmosphere, our CMC walls will not form condensation on the inside, resulting in far less heat loss from the habitat. They are also stronger and much, much lighter than metal.

At the lower front nose of the MER is a rather conventional electric winch, familiar to any off-road enthusiast, and likely to be put to use at some point in time in a place where there are no roads at all. Multifunction manipulator arms are also located on the front and operated remotely from within for sample collection.

EACH MER IS DRIVEN FROM EITHER OF THE TWO FORWARD CAB POSITIONS

Each MER is driven from either of the two forward cab positions – another redundant system – and extensive cameras provide reliable and lightweight 360° viewing around the vehicle. The compact air lock behind the cab provides outside access. An electrically deployed stair rail provides ground access and raises the stairs for maximum ground clearance during transport mode.

Picture courtesy of NASA

The total travel distance on the surface of Mars for our MERs will be great, and the terrain will be variable and challenging. Accordingly, we have incorporated a small, foldaway steering wheel at each of the two cab driving stations in addition to side joystick controllers for the remote manipulators.

All control functions, including steering, are electronic and lightweight. Joystick steering was considered during early design phases, but the driving distances, rough terrain, and fine steering control requirements for our rovers argued for a conventional but small steering wheel. Once the Rover is parked and serving as a habitat, the steering wheel is stowed out of the

Walking on the moon

Recreational vehicles are normally outside the remit of *iVT*, but with the imminent arrival of space tourism, there is a strong likelihood that a lunar leisure vehicle could be in production in the very near future – and require just as high levels of technology as their industrial counterparts. It was with this in mind that industrial designer Alberto Seco produced a concept machine to transport five tourists, while allowing exploration and co-operation with professional astronauts, while minimising environmental impact.

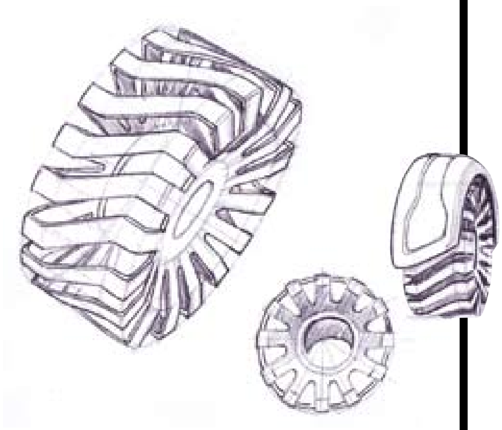
The Moon provides a unique set of requirements for the designer of a moon recreational vehicle (MRV). The footprints left behind by the Apollo astronauts will last for many thousands of years because there is no wind on the Moon. Such a fragile environment therefore calls for co-ordinated four-wheel steering so that turning impact is limited to two footprints produced by turning front and rear wheels in opposite directions. Wide wheels would reduce compaction, and will need perforations and mudguards to minimise the inevitable clouds of dust.

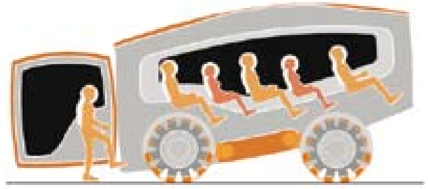
The heterogeneous topography also calls for flexible wheels and variable suspension. As well as providing self-levelling transport height according to the ground conditions, these would allow the

Four-wheel steering will ensure turning impact is limited to two footprints

rear of the vehicle to be placed near the ground for ease of access for passengers and pilot. This self-levelling not only improves comfort, but creates the sensation of 'walking on the moon'.

The body would consist of four panels (two side panels, the roof and the floor, which would also provide a chassis function as it would contain the drive unit), which would need to be of the highest-quality aerospace grade to cope with temperatures ranging from -173°C to +100°C. These panels would be assembled on the 'skeleton' frame once the shuttle had landed on



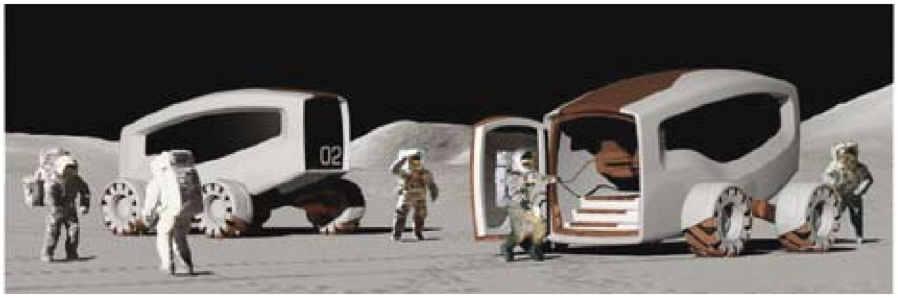


Self-levelling suspension improves comfort while easing access for passengers

the Moon, along with toughened glass windows that would be as large as possible to offer a bigger panorama for passengers. The centrally located driver would also benefit from a big windscreen, improving visibility and therefore vehicle control.

Passenger seats would be distributed to offer a wide central aisle that would give the tourists in their bulky space suits enough room to access the seats. In such an intimidating atmosphere, it is essential to ensure safety by using rounded surfaces – egg and dome shapes are structural masterpieces. Stability would be provided by the suspension arms and wheels around the vehicle.

For further information, please contact: Alberto Seco at albsec@euskalnet.net



way. The two front seats can be rotated 180° to a more accommodating habitat configuration, much like many contemporary motor homes.

Behind the cab and integral air lock is space for two large removable modules, which in this case are a crew module and a lab module. This is the anticipated setup for the MER for most ground excursions. Crew, lab, and other modules can be exchanged with the other MER depending on the particular mission. On top of each crew module is a 360° viewing portal to support the 360° video viewing system, and at key points around the chassis are tool docking stations to support astronauts during their EVAs to explore, collect samples, and service autonomous rovers and other kit.

A planet for the asking

The explorers who elect to make this journey will take risks that will exceed those of all Earth-bound explorers of the past. Having said this, there is a positive element to keep in mind for those of us in the industrial vehicle industry. As Mars' oceans vanished long ago due to conditions having nothing whatsoever to do with humans or human activity, there is an interesting plus side: its total land surface area is equivalent to the total land surface of Earth! There is, indeed, a great deal of space to explore Mars in an industrial vehicle for those willing to do so. **iVT**

FURTHER INFORMATION

www.ergonomicsystemsdesign.com
www.montgomerydesign.com

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