MARSUPIAL
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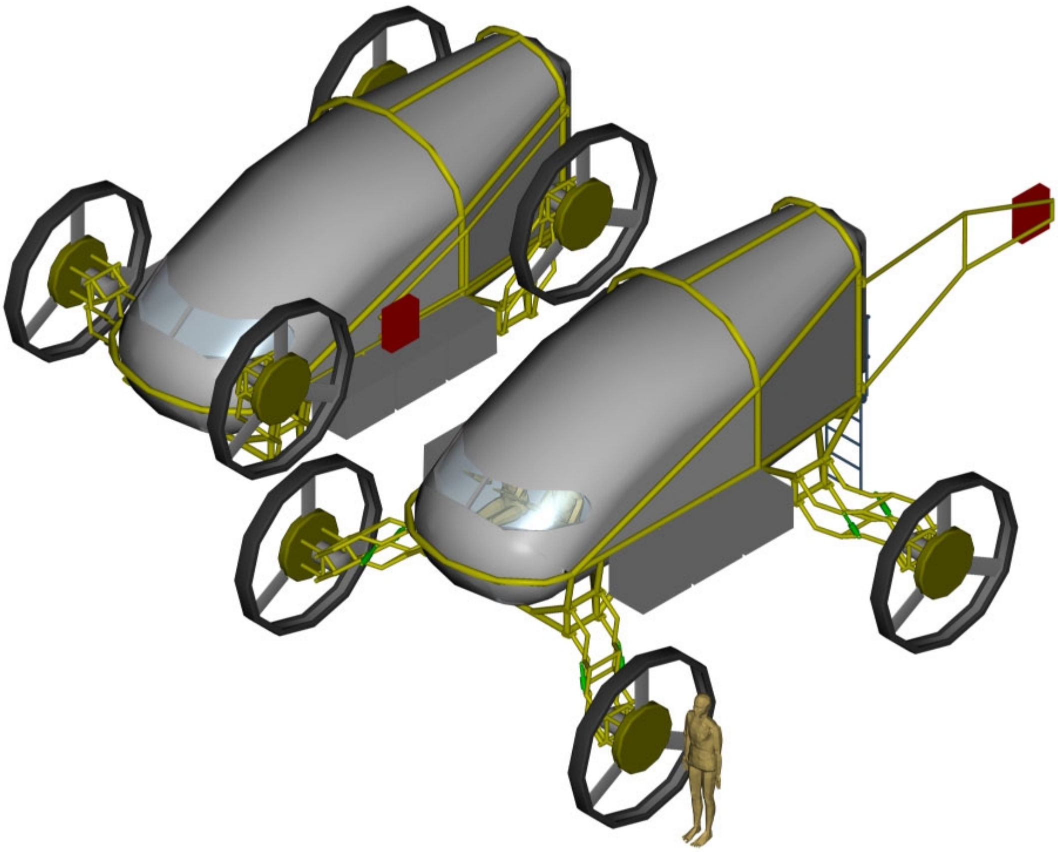


an entry in the Mars Society's

Mars Analog Rover Initiative Design Competition

by

The Mars Society Australia

Contents

1. INTRODUCTION: MARSUPIAL 4

1.1 OPERATIONAL DESCRIPTION 4
1.2 MODES OF OPERATION 5
1.2.1 Solo Operation 5
1.2.2 Accompanied Operation 5
1.2.2.1 U-Rovers 5
1.3 DESIGN PHILOSOPHY: AUSTRALIA AND THE MARSUPIAL 6

2. PROPOSED VEHICLE REQUIREMENTS 6

2.1 VEHICLE STRUCTURE 6
2.1.1 Tyres 6
2.1.2 Suspension 10
2.1.3 Chassis / Frame 11
2.1.4 Pressurized Envelope 12
2.1.5 Pressure Ports 14
2.2 POWER PLANT 15
2.2.1 Engine 15
2.2.2 Electrical System 16
2.2.3 Fuel 17
2.2.4 Speed 17
2.3 EXTERNAL FITTINGS 17
2.3.1 Crane 18
2.3.2 Winch 18
2.3.3 Detachable Tools 18
2.3.4 Sample Stowage 18
2.3.5 Sample Pressure Port 18
2.3.6 EVA Equipment Stowage 18
2.3.7 Manipulators 18
2.3.8 Tow bar Connect 19
2.3.9 Communications 19
2.3.10 Other Fittings 19
2.4 INTERNAL FITTINGS 20
2.4.1 Life Support System 20
2.4.1.1 Waste Disposal 20
2.4.1.2 Water Supply 21
2.4.1.3 Heating, Ventilation and Air Conditioning (HVAC) 21
2.4.2 Furnishings 21
2.4.2.1 Food Preparation 22
2.4.3 EVA Systems 22
2.4.4 Science Systems 22
2.4.5 Vehicle Control 22

3. PERFORMANCE REQUIREMENTS 23

3.1 SPEED 23
3.2 RANGE 23
3.3 VEHICLE MASS 23
3.4 TERRAIN 24
3.5 LOGISTICS 24
3.6 CREW 25

4. SCHEDULE 25

4.1 SPONSORSHIP 27

5. DISCUSSION AND CONCLUSION 29

5.1 MINING 30
5.2 ASTRONOMY 31

5.3 REMOTE SENSING 31
5.4 AUTOMOTIVE 31

6. VIEWS OF MARSUPIAL VARIANT *WOMBAT* 33

7. REFERENCES AND NOTES 37

1. Introduction: Marsupial

This entry in the Mars Society (MS) Analog Pressurised Rover Design Competition is submitted by The Mars Society, Australia (MSA).

We have dubbed our design project, *Marsupial*, a name chosen for the numerous symbolic and literal associations with a pressurized Mars analog rover designed and operated in Australia.

This is a conceptual study and the design for which we have included drawings is the first Marsupial variant *Wombat*[1], an excellent starting point from which to proceed to detailed design of a smaller vehicle. Project Marsupial will develop a range of vehicle concepts, including an interim second hand 4WD van modified to meet the Mars Society specification with an exclusive focus on science objectives.

Other teams for this competition will have developed competent, feasible designs for an analog Rover and we suggest collaboration will enhance the quality and speed of Marsupial detailed design. Delegation of responsibility for some vehicle systems to international groups is expected to improve our prospects for securing funding from multinational corporations and governments.

1.1 Operational Description

See 6 for view of our primary concept vehicle. Marsupial is a mobile geological, meteorological, and exobiological station. It is designed to allow a crew of 2-3 to traverse the Martian terrain for periods of up to one week, performing scientific activities and collecting samples and data for further analysis at base camp.

Marsupial is designed to operate at greatest capacity when accompanied by one or more unpressurized rovers (u-rovers). Attachment of these could be via tow bar or by carrying under the main vehicle belly. Onboard features will also allow for effective unaccompanied operation, on general exploratory sorties or when scouting for sites of interest.

We have chosen *mobility* as the highest priority, over functionality. Therefore our design is based on large wheels and a high clearance profile, with independent struts and electric motors for maximum All Terrain (AT) capability, especially through rock fields.

Functionality (e.g. the addition of external and internal equipment) is considered desirable but when mass trades are made in detailed design of a real Mars rover, we suggest mobility will take precedence. It is important to note that Marsupial is designed with an exoskeleton cage to allow addition of external fittings such as a remote manipulator arm (RMA) and sample/tool boxes, and the internal design will be modular allowing configuration changes during and between operational campaigns.

We have a clear mission for project Marsupial. It serves two purposes:

Science

- A platform for high fidelity human simulations undertaken by members of the Mars Society that looks, feels and functions like a real Mars rover, and

Engineering

- A platform for testing a particular rover configuration concept to contribute to the international design database for pressurised rovers to be used in the first human Mars missions and encourage greater Australian participation in international space exploration efforts.

These dual aims are complementary yet will be managed to ensure a balance is struck and that the objective of operating the vehicle in Australian Mars analog environments in 2002 is achieved.

Finally, and importantly, we hope Marsupial will form the locally-designed hardware component of an Australian Mars Simulation Facility (AMSF) analogous to that established on Devon Island.

1.2 Modes of Operation

Marsupial has two primary modes of operation.

(a) solo operation, in a scouting or basic exploratory capacity, and

(b) accompanied operation, where a greater variety of exploratory approaches is achievable.

1.2.1 Solo Operation

In this mode, EVA excursions are limited in range and the pressurised rover undertakes the bulk of territorial traverse. During EVA, Marsupial will typically remain stationary.

1.2.2 Accompanied Operation

Unpressurised rovers afford greater mobility and range for EVA crewmembers. The high clearance of Marsupial leaves a number of possibilities for u-rover transport. In the Wombat variant, two u-rovers can be attached to the belly and carried cleanly from the ground. In the smaller variant we wish to build, space for just one will be available.

1.2.2.1 U-Rovers

Marsupial will eventually be accompanied by 1-2 small recreational vehicles (3 or 4 wheeled) as part of a proposed AMSF. such as those currently used at the Devon Island

1.3 Design Philosophy: Australia and the Marsupial

Rather than commence design of the Rover immediately around compromises required for Earth analog operations (e.g. use of an existing chassis), we have chosen first to design an actual Mars vehicle for use in initial human landings, *then* to make compromises necessary to realise its construction and operation.

Marsupial will contribute not just to Mars human surface operations simulations, but also to the design of a key element of Mars mission architecture. We plan to use the project to mobilise wider participation in MSA and crystallise Australian aspirations for a greater role in space in a "down to earth" manner. It is a unique opportunity to widen interest in Mars amongst the Australian engineering and scientific community.

Marsupial campaign teams will have ready road and trail access to some of the world's best Mars analog terrains.

Australia's arid central regions contain vast areas of rocky and sandy terrain, similar to the Martian surface. Dr Malcolm Walter, author of "The Search for Life on Mars" will act as a consultant and will help us identify the best sites. Australia also has a significant presence in the Antarctic, and the possibility exists for cooperation with the Australian Antarctic Division based in Tasmania to undertake polar campaigns.

2. Proposed Vehicle Requirements

The use of an existing chassis is clearly the cheapest and easiest solution for achieving Marsupial's s*cience* objective, however a custom platform design is necessary in the effort to achieve our *engineering* objective.

A custom vehicle also maximises the realism of scientific simulations.

2.1 Vehicle Structure

2.1.1 Tyres

Marsupial has four wheels, each approximately 2m in diameter and consisting of a spoked wheel with a solid rubber tire. Inflatables are desirable on Mars since they add an extra level of compliance and provide high frequency vibration filtering for improved crew ride comfort, however for simplicity we will use a solid yet compliant rubber tyre. The availability and reliability of inflatable tyre technology for the extreme Mars surface conditions coupled with the rigours of AT operation is uncertain.

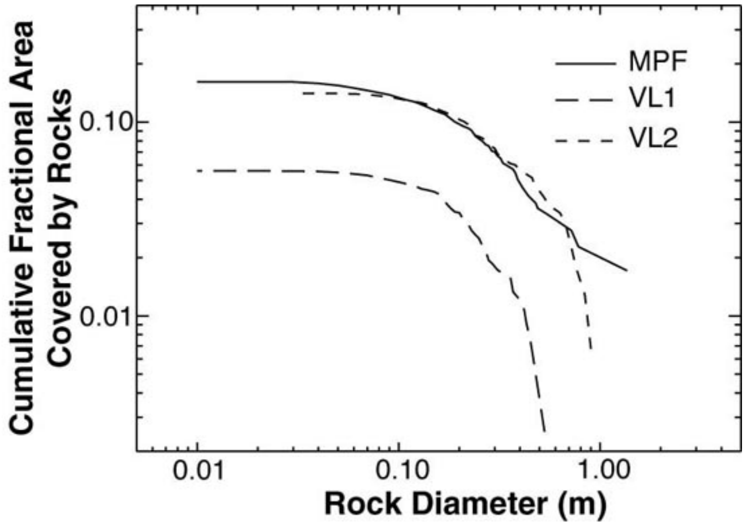


Figure 1 Cumulative size-frequency distribution measured from stereoscopic photographs on Mars Pathfinder (MPF) and the Viking 1 and 2 Landers (VL1 and VL2)[2]

Rocks have been strewn across the Martian landscape by meteor impacts and volcanic ejections and a lack of erosion mechanisms sees more numerous rock fields than here on Earth. Figure 1 shows the only detailed data we have on localised rock size distributions. Those of diameter > 100 mm cover 5.0% – 10.5% of the area characterised, while rocks of diameter > 500 mm cover 0.2% - 4.0%. These are substantial fractions and if the pressurised rover is not capable of traversing them, access to these scientifically interesting areas is severely limited.

In such fields, it is impossible to steer around every > 100 mm rock and large wheels smooth the vehicle terrain profile response. Passenger comfort is maximised and impulsive structural stresses are minimised when large, inflatable tyres are used. Large wheels also reduce the vehicle cone index (VCI), important for traverse through sandy soils.

The design decision to adopt large, unconventional wheels and provide maximum mobility does present a major challenge to Marsupial - practically the entire wheel assembly must be custom manufactured. Although a difficult decision, it is consistent with our engineering objectives, and manufacture of the assembly in Brisbane is considered feasible.

We plan to engage all of the following manufacturing centres:

- the Queensland Manufacturing Institute (http://www.qmi.asn.au/),
- the Cooperative Research Centre for Alloy and Solidification Technology (CAST) (http://www.dist.gov.au/crc/centres/man/ast.html), and
- Advanced Composite Technology Pty. Ltd. (http://www.adcomp.com.au/), who have contributed to the successful

SunShark (http://www.uq.net.au/sunshark/frame.htm) solar racing team at the University of Queensland

We currently favour use of a carbon composite rim and spokes, coupled to closely fitting aluminium alloy cast planet and ring gear carriers, containing machined and heat treated aluminium alloy spur gears.

However, tyre material selection is a major issue slated for special attention. We will continue to investigate options for improved tyre compliance and vibration filtering, such as with an Apollo-like metallic mesh covering spring belts or with a layered hard surface, soft-core material option. A softer tyre must be wider to reduce the contact pressure and rate of wear, especially in rocky environments. A hard yet compliant outer surface material in combination with a wider rim may resolve the issue. Wombat currently uses a 200 mm wide rim, which may need to be increased in the smaller variant depending on the outcome of a more detailed theoretical analysis and ideally of laboratory testing.

Six wheels would reduce the nominal ground pressure and enhance AT capability yet the extra two wheels add undesirable weight. The cost/benefit ratio in stepping from four to six is most significant for smaller wheels (e.g. Pathfinder class robotic rover), less so for larger wheels.

A special feature of Marsupial is the use of a planetary gear system incorporated into each wheel hub. Again, the selection of a large wheel option requires custom designed, machined and treated (e.g. case hardened) lightweight alloy gears and supporting structure. This is a considerable challenge for a low cost project but one we are prepared to pursue.

It is desirable that Marsupial, upon meeting a large rock or sudden incline, can "crawl" or "walk" up and over the obstacle. If we imagine slowing this process down the situation tends toward static equilibrium and calculation sheets are attached showing the basis of a simple two-dimensional parametric spreadsheet model that gives the nominal torque required on each wheel.

This assumes the entire vehicle is held at some angle $\Delta\phi$ (the *obstacle traverse angle*) beyond the initial contact angle ϕ made by the 2-D front wheel of radius r_w and a circular obstacle of radius r_0. A critical parameter is the friction factor μ (which can be interpreted in the spreadsheet as the static value for torque calculations or the dynamic value for power calculations), set at 0.25 for rubber-rock friction and an arbitrary assumption is made to close the system of equations (in this case that the reaction forces on the front and rear tyres is made equal).

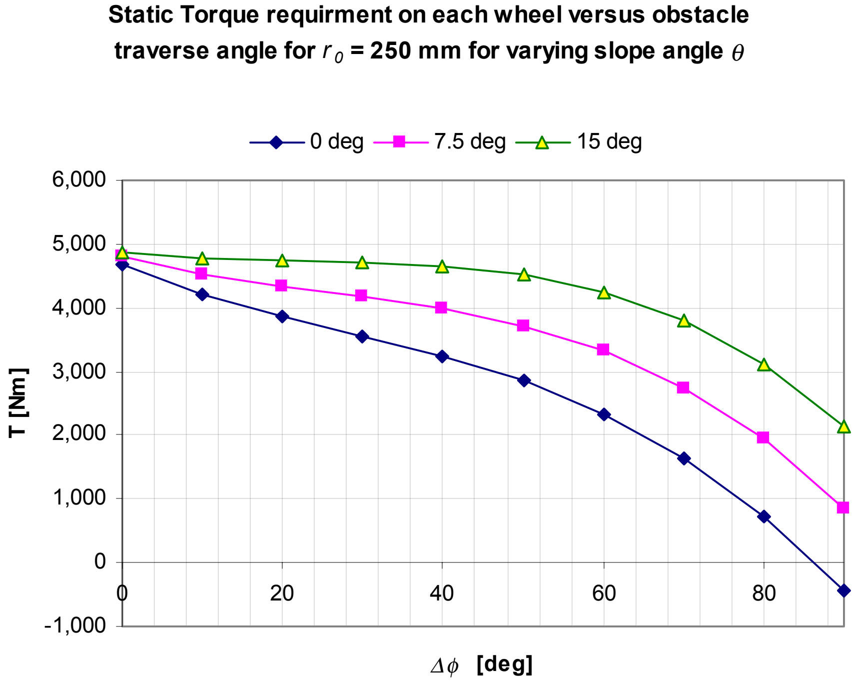


Figure 2 Variation of static torque required for the front wheel to maintain its position, with changing obstacle traverse angle and overall slope. Note that the torque is highest when the vehicle starts on a steeper slope and has just made contact with the obstacle. Although this is only a first order calculation, it does illustrate the trends and highlights the potentially large torque requirement. The assumption of equal reaction forces on each wheel leads to the negative torque when on the flat.

A typical electric motor for the current application can provide a maximum torque of around 100-300 Nm. The order of magnitude difference indicated by Figure 2 suggests the need for a gear train to reduce wheel speed and increase torque substantially.

Torque values in Figure 2 are conservative yet a gearing ratio of 46:1 is possible in a relatively narrow envelope of 900 mm diameter. A first order calculation (Figure 3) shows that use of a small module m = 1.0, 20 mm diameter sun gear carrying 20 teeth, meshing with three primary planet gears each of diameter 440 mm, coupled to three secondary planets each of 80 mm diameter and engaging with an internal ring gear of only 540 mm diameter can produce the desired speed reduction[3].

Parameter	Symbol	Value	Units	Value	Units
Motor Rotational Speed	ω_1	-	[RPM]	-	[Hz]
Motor Torque at this Speed	T_1			100	[N][m]
Vehicle Velocity	V	0.0	[km]/[hr]	0.00	[m]/[s]
Wheel Radius	r	1,000	[mm]	1.00	[m]
Wheel Rotational Speed	ω_a			0.00	[Hz]
Speed Ratio	i_0			0	
Module size	m			1.00	[mm]
Number of teeth on Sun Gear	z_1			20	
Number of teeth on Second Planet Gear	z_3			80	
Ratio of First Planet to Sun	σ_{21}			22.00	
Torque Ratio	T_a/T_1			-46.00	
Output Torque	T_a			- 4,600.00	
Diameter of Sun Gear	D_1	20.00	[mm]		
Diameter of First Planet(s) Gear	D_2	440.00	[mm]		
Diameter of Second Planet(s) Gear	D_3	80.00	[mm]		
Diameter of Ring Gear	D_4	540.00	[mm]		
Diameter of Gearbox Envelope	$D_1 + 2D_2$	900.00	[mm]		
Radius of Sun Gear	R_1	10.00	[mm]		
Radius of First Planet(s) Gear	R_2	220.00	[mm]		
Radius of Second Planet(s) Gear	R_3	40.00	[mm]		
Radius of Ring Gear	R_4	270.00	[mm]		
Radius of Gearbox Envelope	$R_1 + 2R_2$	450.00	[mm]		

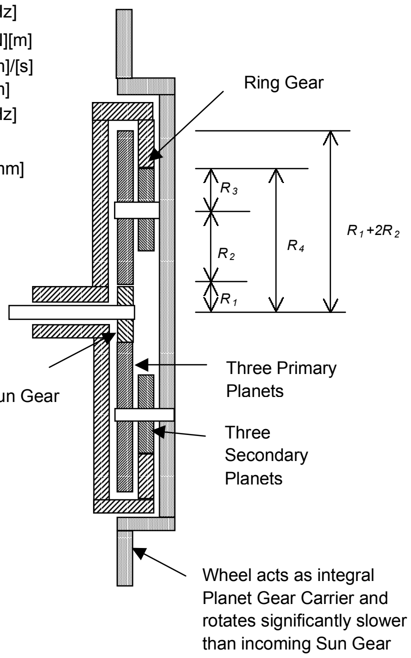


Figure 3 First order design calculation for a planetary (epicylical) gear train. More detailed calculations accounting for tooth fatigue and pitting and more evenly distributing loads will be needed to finalise module selection and gear sizes.

2.1.2 Suspension

Each wheel is attached to the vehicle frame by a suspension system of two parallel “wishbone” struts, connected dual dampers and a single coil spring. We are interested in the use of VPD’s, allowing Marsupial to be raised or lowered to adapt to the terrain (higher during slow walking through rock fields and lower during faster traverse over smooth terrain). This would also provide another degree of freedom whilst reversing the vehicle if rearward docking to a main hab is desired.

The suspension arms are hinged at each end with a single cross bar on each of the upper and lower portions for strengthening. Hollow aluminium tubing of 50 mm diameter is currently specified, and resistance to impulsive torques vertically transverse to the longitudinal hinges is a key engineering issue (e.g. incurred as the vehicle contacts obstacles at speed).

The arms themselves are made up of straight welded sections for ease of fabrication, although further Finite Element Method modelling may suggest the need for curved arms. The complex segmented design allows compact folding of the entire arm and wheel assembly upwards during transit packing. The Wombat variant fits within the rectangular packing envelope specified for this competition.

Dampers will be connected via ball and socket joints to the outside of each strut system arm. A flexible material (not shown in our drawings) will cover the entire suspension arm, secured by Velcro strips, and slightly pressurised by cabin bleed air (or the VPD gas if different) to exclude the very fine Martian dust and extend the life of critical moving parts, reducing the need for active lubrication systems. Movement of the arms during driving and the bellows effect will need to be considered in ensuring positive exclusion at all times.

Deployment of the arms will be automated if possible using a low-technology system for maximum reliability. Passive energy release by the folded VPD’s is the most desirable solution, requiring minimal crew involvement.

VPD’s may not be included if they are not feasible on Mars. Some key issues to be investigated more fully include the nature of the VPD gas (or liquid) and its behaviour in the extreme Martian conditions, and the pressurisation system required (if gas is used). This is an example of the way MSA hopes to make an engineering contribution to the design database for initial human rovers - should VPD’s prove feasible in principle, Marsupial would demonstrate the value of variable ride height functionality in simulated operations.

In the Wombat variant, the nominal wheel footprint is approximately a 4.2 × 4.2 m square. A feature of the design is the wide wheel base, maximising AT capability, minimising the risk of tipping and offering substantial clearance. A VPD system would allow changes in ride height and even differential shifts between the front and back clearances while driving, offering real time active centre of gravity control.

2.1.3 Chassis / Frame

Marsupial's cabin will be surrounded by an 'exoskeletal' frame, designed to:

- reduce stresses on the cabin envelope, perhaps resulting in an overall mass reduction especially in view of the fact that a monocoque cabin design must accomodate severe stresses during rugged terrain operation (e.g. crawling through rock fields),

- provide attachment points for external tools and possible carriage of 1-2 u-rovers under the belly.

and currently specified as 75 mm diameter, 5 mm thick aluminium tubing. The exoskeleton and cabin structure is probably simpler to fabricate than a monocoque construction and offers a wider range of choices in the selection of the cabin skin material. We will approach aluminium fabrication shops to help produce the frame, in parallel with construction and/or moulding of cabin sections, perhaps in a different facility. Monocoque construction would require more specialised facilities and personnel.

2.1.4 Pressurized Envelope

The cabin shape and the suspension/wheel configuration is the starting point for the design. Curved surfaces offer the lowest mass to volume ratio. Our initial concepts focussed on a “pill” cylinder with sphere cap ends. However, space here is wasted at the front where crewmembers merely need to be seated for driving. The aft sphere cap requires a major shaping compromise to accommodate a realistic egress door, unless a small circular door is used. Finally, the forward suspension arms can be folded up and *over* the “pointed” cabin nose, while a tapered aft section can accommodate folding of the back suspension arms.

Space on the first Mars human transfer vessels will be at a premium. The shape and volume of the packing envelope will be one of the primary determinants of rover shape, and we suggest designers will not hesitate in using a non-cylindrical topology if packing is improved or it better suits the needs of the rover crew, since very light, strong materials will be employed. For example, a simple sphere was the most mass efficient topology for the Apollo Lunar Module, yet for a range of reasons and following a succession of trades, what emerged from the Long Island design offices of Grumman Corporation was a complex, non-spherical shape. We are not arguing necessarily in favour of such an approach, (for the Russian Soyuz capsule, the most long lived of all spacecraft structural designs, demonstrates that simplicity can be effective), the point is that a complex topology for a future Mars rover is conceivable and even that it is probable.

Thus the Marsupial nose is pointed, accommodating two, seated side-by-side crew for driving. A thin narrow window, strengthened by a central spar, provides a wide-angle view for the crew. In fact the view afforded from this raised vantage point (nominally 3-4 metres high) is a major advantage of Marsupial. Two small teardrop shaped windows on each side of the nose at their feet offers crewmembers a view of the terrain below. Window space must be minimised since they typically require a relatively heavy material and breaches of the pressurised envelope reduce structural strength. The accumulation of dust on windows, especially the angled main driving window, is a non-trivial issue and mechanical wipers will be included.

The transverse width allows a 1.8 m tall crewmember to lie comfortably sideways in the cabin, removing one constraint on its longitudinal length. We favour a single aft egress door 1.7 m high by 700 mm wide that can accommodate a 1.8 m tall crewmember only slightly stooped when fully suited. If ingress/egress are to be performed several times each day, crawling through a small circular door is undesirable while larger diameter circular doors are wasteful (since only a suited human shoulder width must be accommodated).

This design decision requires that the rest of the cabin follows a transition from an ellipsoidal nose to a somewhat rectangular aft profile, noting that the shape must be convex at all points for minimum weight/maximum strength.

An additional constraint was that some portion of the mid cabin sidewall remained aligned longitudinally, to allow support for major external tools such as a drill. However, in deciding to focus on mobility over functionality these major external fittings are now less imperative and the smaller variant may taper the entire sidewalls backward. In this case cabin width and height will be similar – only the length will be shortened.

Where possible all radii of curvature are large, however the tightest curve occurs midships at the transition from the straight sidewalls to the tapered aft wall. We favour incorporation of an airlock wall and door (see below) into a real rover, and this transition is an ideal location for a major internal bulkhead, separating the cabin into two sections, coupled to a major exoskeleton spar and acting as a central load-bearing anchor. However, it must be emphasised that in the analog vehicle, an airlock wall need not be included and that a light, simple, plywood structure can simulate the wall and door if necessary.

A central stepped floor of 400 – 500 mm height will allow containment of tanks, batteries and the fuel cell bank if this is used (all within the pressurised envelope for better access and maintenance). This will allow a 1.8 m tall crewmember to stand fully upright in two limited spaces – near the transition adjacent to the airlock wall (if fitted) and near the egress door for suiting up/down and dusting off. An ability to stand upright inside the cabin, even if constrained, is important on week long sorties.

The Wombat variant provides an internal volume of the order of 15 m^3, and the smaller variant will reduce this figure, recognising that human Mars mission designers will need to be ruthless in adhering to extremely demanding mass budgets. As such, Wombat is actually regarded as a 4-man vehicle – the smaller variant we wish to build will be exclusively 2-man with capacity to accommodate 4 in an emergency or for transport purposes only.

While Marsupial appears streamlined, aerodynamics are not an issue on Mars and the shape is entirely a function of:

- human metrics,
- the selected suspension arm and wheel configuration and
- the specified packing envelope

Finally, material selection for the cabin is yet to be finalised. Candidates include:

- a thin aluminium skin riveted in sections to aircraft-like aluminium bulkheads,
- a dual skin, aerospace honeycomb design with an overall thickness of 20 – 30 mm attached to similar bulkheads,

- plywood sections attached to wooden or aluminium bulkheads, and
- a moulded composite, joined by mechanical flanges with a lesser need for minor bulkheads.

The option selected will depend mainly on our financial and time constraints, and interest from potential fabrication facilities.

Fire safety is an issue for Marsupial, and for this reason a plywood option, although probably the cheapest, is not favoured. The forward cabin may need to include an emergency egress door, while 2 fire extinguishers will located at either end of the vehicle.

2.1.5 Pressure Ports

Although the design specification calls for depressurisation of the entire rover in initiating most EVA activities, we suggest the decision to exclude an airlock is marginal and that the benefits may outweigh any mass penalty.

The airlock wall in our design may actually be advantageous as a central bulkhead for absorbing cabin stresses transmitted by the exoskeleton during rough terrain driving. The airlock creates a natural barrier between a forward "clean" living and vehicle operations area, and an aft "dirty" workshop and EVA operations area. Dust control will be one of the most significant design issues for all Mars surface systems, and the compartmentalisation created by an airlock will assist greatly in containment.

Additionally an airlock will allow one crewmember to undertake EVA while another remains in a shirt sleeves environment with ready access to vehicle systems should an emergency arise, and for improving the productivity of the sortie with ready access to information.

We reiterate that an airlock is not an essential component of this design and that the requirements of the Mars Society competition specifications can be met.

2.2 Power Plant

Vehicle drive power requirements are dictated by the coefficient of rolling resistance (CRR). For rubber on a hard surface (such as rock), CRR ~ 0.25 while for soft sand, CRR can be as high as 0.6. We size the nominal drive system for a flat traverse with the average (CRR ~ 0.45, V ~ 16 km/hr) and peak conditions (CRR ~ 0.6, V ~ 32 km/hr) expected. With a 1,500 kg dry vehicle and a total 1,500 kg payload including one u-rover (3,000 kg gross), this gives a nominal peak power requirement on earth of 157 kW, and a nominal average of 59 kW. These figures become 219 kW and 91 kW respectively for a 15° upward slope. However, since an uphill maximum speed was not specified, dropping this from 32 km/hr to 22 km/hr leads to a more reasonable peak hill power of 151 kW. We therefore require an overall peak power of around 150 kW and an overall average somewhere between 60 and 90 kW, or 75 kW.

These simple calculations have been implemented in the spreadsheet used for the vehicle static force model.

2.2.1 Engine

We will employ a serial hybrid electric drive system with one power source, either an internal combustion engine (ICE) or a natural gas ceramic fuel cell (CFC). On a real Mars rover, should an ICE be chosen we suggest the use of two smaller engines, for redundancy and parts cannibalisation in the event of component failure. CFC's are more energy efficient (80% compared with 25%), make direct use of a readily manufactured Martian fuel source (methane), require a smaller battery bank and with no moving parts and high reliability, redundancy needn't be considered.

Power density has been the main drawback for fuel cell technology however the CFC solution offers some hope as a light option for our mobile rover application. For the purposes of this concept submission, cost, simplicity and risk considerations suggest a single, reliable ICE as our first option, with serious consideration given to a CFC solution if it can compete on cost and mass for the same power output.

ICE Option

We favour the use of one of the new generation of four cylinder turbocharged diesel light aircraft engines, such as that promoted by DeltaHawk Inc, of Racine, Wisconsin (http://www.deltahawkengines.com/). The DeltaHawk V-4 is designed to be light, compact and fuel efficient, fitting within an envelope 59 cm (23 in) wide by 49 cm (19 in) high and 68 cm (27 in) long, with a full system (including liquid coolant and oil) mass of 140 kg (310 lb). Modifications will be necessary for hybrid use with a generator, although these are not expected to be significant. Cost for this modified system ranges up to US$20,000, and local providers of similar high performance products will be approached.

ICE noise will be a non-trivial issue on Earth and on Mars. Depending on the cabin materials chosen, structure borne noise may necessitate isolation mounting. An acoustic barrier around the engine block will be needed. Should these measures prove inadequate, there may be scope for an active noise control system to be developed as a student project under the supervision of Associate Professor Jie Pan[4] at the Department of Mechanical and Materials Engineering, The University of Western Australia (UWA) in Perth.

The ICE will be located in a separate acoustic box in the centre of the aft section. The use of an airlock wall would add another measure of sound control for the crew. An air intake and external mechanic access door will be located directly beneath the engine on the vehicle aft belly. The exhaust pipe will be directed outside the cabin to one side and probably extended upward for emission near the top surface of the vehicle. An air intake will be designed for the belly of the vehicle (so as not to interfere with u-rover attachment) for engine ventilation and cooling via a radiator. The intake will form part of a door providing access to the engine and battery bay for a mechanic between operational sorties.

The ICE will be run at a small number of discrete speeds for optimum fuel efficiency for extended periods with automatic control to maintain peak health of the engine and electrical system. The actual engine power capacity chosen will depend on final hybrid system design which in turn will depend on the total power budget, using tools such as the freely available Advanced Vehicle Simulator (ADVISOR[5]).

Alternate Options

Marsupial provides an ideal platform for companies seeking to promote innovative products, such as the Canadian Quasiturbine low emission, zero vibration rotary engine[6]. Incorporation of novel and green technologies into Marsupial is an important strategy for mobilising local public, academic, commercial and political support.

Australia has a strong commitment to sustainable energy technologies[7] and Marsupial will ultimately seek to incorporate or retrofit clean systems being developed in various centres around the country[8]. For example, CSIRO Division of Manufacturing Science and Technology based in South Australia is a world leader in fuel cell technology with development of a 5 kW solid oxide fuel cell stack, powered by natural gas. The system is readily scalable and a 100 kW stack is planned for operation by mid 2001. MSA will seek to work with CSIRO and its spin-off company[9] to use Marsupial as a high profile international demonstration platform of the technology.

2.2.2 Electrical System

Each wheel motor must have an average power output of 75/4 = 18.75 kW and a peak output of twice this figure (37.5 kW). This is not a difficult specification to fulfil and we will seek the lightest, highest torque COTS system (motor and controller) possible.

At least two circuits will be used, separating the vehicle power train and all on board control and housekeeping electrical systems. A power conditioning system will be needed for all systems.

A battery bank will be used, and a DC electrical system powering pulse-modulated electric wheel motors is currently favoured (these provide higher torque capability amongst other benefits). On both Earth and Mars, heat dissipation may be a challenge. On Mars, the low atmospheric density may necessitate an active cooling system, the adequacy of passive fins for Earth operation in the nominally arid environment must be determined. Antarctic operation will feature in motor selection criteria, although this is expected to be less onerous.

Two spotlights will be located on the nose frame, with another located above the egress door.

2.2.3 Fuel

The specified range of 320 km, completed at an average speed of 16 km/hr gives a total of 20 hours of driving, or 2.86 hours per day over a week. In the case of a 150 kW (200 hp) DeltaHawk V-4 engine, the fuel consumption at 65% peak power is 26.5 l/hr, giving a total consumption of 530 litres or 435 kg with a specific gravity of diesel of 0.82. The nature of the tank(s) is yet to be determined – most passenger vehicle diesel tanks are steel with a capacity not exceeding 100 litres. The cheapest option would be to find a 550 litre second hand tank, however the weight is likely to be excessive. Also, multiple small tanks are best for centre of gravity distribution but may introduce added complexity.

2.2.4 Speed

All systems described above have been designed to accommodate all-terrain travel of at least 8 km/hr ("walking" mode over rock fields), with an easy-terrain maximum speed of 32 km/h and an average speed of 16 km/hr per sortie. Up a 15° grade, Marsupial will make 22 km/hr on smooth terrain.

2.3 External Fittings

Our criteria for external fittings include:

(a) it must either be operable from within the pressurized vehicle, or

(b) the fitting must enhance the basic scientific or exploratory functions of the vehicle without adding excessive weight or power requirements.

The use of VPD's would allow the vehicle height to be lowered where possible during EVA to reduce the risk of falling from the egress door ladder, and to provide easier access to external fittings, particularly sample/tool stowage and the sample pressure port.

2.3.1 Crane

A crane has not been included in this conceptual design of Marsupial, although it is intended that a Remote Manipulator Arm (RMA) capable of acting as a crane will fold up on the starboard side of the tapered aft section. An additional window (perhaps a bubble) would be included on this side, with internal control via a joystick.

2.3.2 Winch

Again, this is a desirable item but one that can be retrofitted. It would be positioned centrally under the nose, where the exoskeleton frame would absorb the winch load. It is likely a geared manual handle would also be specified for this COTS item, as a backup.

2.3.3 Detachable Tools

These are essential for the science objectives of Marsupial and will be positioned on the side of the vehicle. Although elevated, they would remain within reach of EVA crewmembers, and with the use of VPD's, could be readily lowered to waist level.

2.3.4 Sample Stowage

Marsupial will be fitted with the specified number and volume of sample storage containers along its sides.

2.3.5 Sample Pressure Port

A Sample Pressure Port may be desirable to facilitate EVA work, and would be located adjacent to the RMA, opening into the aft section. This has not been detailed in the current design, but can be incorporated.

2.3.6 EVA Equipment Stowage

Marsupial will be fitted with one external EVA equipment storage container, approximately 30cm wide by 30 cm high by 1.2 m long, fitted along the side of the vehicle along with items 2.3.3 and 2.3.4.

EVA suits and other equipment will be stowed in the aft "dirty" section of the cabin.

2.3.7 Manipulators

The RMA will probably be electric, and is considered one of the primary external fittings. It allows site inspections and sample collection without the need for EVA, greatly increasing exploration productivity. We will seek agreement with an international MS group to design and manufacture the arm for integration onto Marsupial.

2.3.8 Tow bar Connect

Two towing options include:

- Trailing u-rovers (possibly daisy chained) connected via an A-frame arm to a tow ball on the rear belly of Marsupial, aft of the engine air intake/access door. The frame would fold for stowage in external holds.

- Slinging 1-2 u-rovers to hard attachment points beneath the belly of Marsupial. An electric or hand-wound winch with three cables per u-rover would be fitted to the belly exoskeleton and used to lift each vehicle for manual hard-locking.

In the latter case, the reduction in Marsupial ground clearance would depend on u-rover geometry, although over medium and smooth terrain this would not significantly limit mobility (it would in fact have the benefit of lowering the centre of gravity). In rough terrain, the VPD's could be activated to raise the clearance of the Marsupial-u-rover combination.

2.3.9 Communications

The baseline system will include a VHF radio for voice communication with base and local EVA exchange. Ideally, realtime audio, video and medium bandwidth data transmission to base (up to a range of 160 km) will be incorporated to provide a realistic simulation environment, and while these systems will be considered in detailed design, the point at which these 2nd tier COTS items are fitted to the basic platform will depend on resource availability. A whip antennae will be fitted to the exoskeleton, capable of folding back during packing.

We also propose the purchase of a satellite phone for base camp operation to allow co-ordination with a simulated Earth mission control in the United States or Europe during Australian operational campaigns. A signal delay representative of Mars-Earth transmission (~ 40 minutes) would need to be simulated.

2.3.10 Other Fittings

A Ground Penetrating Radar (GPR) is an ideal, relatively light external item for a real Mars rover. The Wombat variant is shown with a swinging arm boom supporting the antennae package (the boom could be manually deployed and locked into place to reduce the need for an electric motor).

GPR allows examination of subsurface discontinuities in the dielectric constant, used to identify features such as a water table to depths exceeding 1,000 metres. Further, a GPR unit attached to the vehicle will allow rapid survey of the subsurface characteristics of a large area. A boom (possibly made of composites) is necessary to reduce interference from metallic vehicle structures. Dr Glenn Stickley from the University of Queensland node of the Cooperative Research Centre for Sensor Signal and Information Processing (CRCSSIP[10]) has advised that the GPR antenna package need only weigh of the order of 50 kg, with some electronics necessary for interpreting the data.

2.4 Internal Fittings

Moving aft from the nose of the vehicle, internal fittings consist of:

(a) A cockpit with driver and passenger seats side by side,

(b) A storage section with space on either side, approximately half of which will be for scientific equipment, with the other half reserved for food, medical supplies and other consumables. These storage containers will be raised above the floor or will include removable lower sections to allow for the crew to sleep partly underneath them.

(c) A short habitation section allowing seating for an optional third crewmember and a small workspace, serving as a combined dining and sleeping area.

(d) Finally, there will be a toilet/bathroom unit on one side, and a small food preparation unit on the other.

The main cabin will be a 'clean' area, and the aft section, a 'dirty' area where dust contamination (and frequent depressurisation if this is designated as an airlock) can be managed. The aft section will house EVA suits, workstations for examination of samples (e.g. a microscope), and the engine. This leads to the inward-opening single rear egress door. The sample pressure port will consist of two doors, one breaching the cabin envelope, the other internal with the port.

2.4.1 Life Support System

2.4.1.1 Waste Disposal

The appreciable gravity of Mars (0.38g) will not necessitate highly specialised waste disposal facilities. Marsupial will include a COTS toilet with hand pump, similar to those found in campervans and yachts, surrounded by a draw curtain for privacy.

Humans produce approximately 1.84 litres of bodily waste per day, on average.[11] This equates to around 13 litres per crewmember on a one-week excursion,. Accounting for the possibility of up to four crewmembers, we could therefore use a tank all but identical to the fresh water tank (see 2.4.1.2) of 60-65 litres.

2.4.1.2 Water Supply

Humans require an average of approximately 2 litres of water a day for drinking. Each crewmember will thus require an average of 14 litres of drinking water for a one-week excursion. During strenuous activity, and especially in the hot conditions of Australian analog sites, this figure must be increased by a factor of 2-4. In addition, water will be needed for sponge bathing and food preparation. Capacity must also account for emergency simulations with four crewmembers. Overall, we estimate a capacity of only 60-65 litres will be needed on Marsupial.

A COTS caravan or yacht water system with a plastic tank and manual hand pump will be used. A valve will allow external drainage of the tank, important to reduce the risk of tank contamination between operational campaigns.

2.4.1.3 Heating, Ventilation and Air Conditioning (HVAC)

Marsupial will be designed for a wide temperature range since candidate Australian analog desert sites can be cool at night (~ 0°) and hot to extremely hot (~ 25° – 45°) during the day depending on the time of year. A HVAC system is therefore essential. Sites will be chosen mainly for their Mars-like terrain, but also for their low rainfall during operational campaigns.

A second-hand stand-alone automotive gas-cycle airconditioner unit is the most feasible initial solution for Marsupial. This would be run off the ICE, with a separate radiator within the same air scoop used by the engine. If the fore (clean) and aft (dirty) cabin sections are separated either by an airlock wall or curtain, a channel will direct conditioned air into the forward area for maximum effectiveness.

Small hinged or sliding ventilation doors will be provided on each side of the nose of the vehicle and on the top of the forward upper curved section (near the cabin transition point), in case the temperature exceeds the airconditioner capacity. The airconditioner will also provide heating when necessary.

2.4.2 Furnishings

The forward cabin has side-by-side seating for two in the cockpit. This will include a small workspace adjacent to the passenger seat allowing operation of a notebook computer or similar-sized tools.

The mid cabin, behind the cockpit and storage sections, will be a combined dining and sleeping area. This section will have fold-down seating for two, separated by a small removable table. Crewmembers will sleep across the cabin either on side by side folding mats laid down on the floor or else stacked one on the other on removable stretchers attached to the sidewalls. Sleeping space in this section is sufficient for only two crewmembers: additional crewmembers will sleep in the driving seats of the cockpit, which will have a reclining function.

2.4.2.1 Food Preparation

A "kitchen" bench will be included on the opposite side of the mid cabin to the toilet/bathing facility. This bench will include a preparation area and a small sink with the manual water pump.

Initial sorties of Marsupial will use cold pre-prepared food. Space will be set aside for the future inclusion of a small microwave oven. This will also be considered in design of the electrical system, since readily available COTS microwave ovens use AC.

Draw-based storage space will also be included for essential utensils.

2.4.3 EVA Systems

Rather than using a specialised one-piece custom suit-docking system, standard multi-component EVA suits will be housed in the dirty aft section of Marsupial. We expect these will be bulky, particularly if four units are carried, and the aft section will have room for a suit hanger, donning/doffing space, a scientific workbench, engine box (the space above which might be used as a utility table or for the suit cabinet), sample storage boxes adjacent to a possible sample pressure port, a standing joystick control port with window views for the RMA and rearward hab docking operation, and the inward swinging egress door.

2.4.4 Science Systems

Marsupial need only initially be equipped with basic equipment needed for first order geological analyses and site surveying, to allow crewmembers to complete a realistic daily routine for simulation purposes. These basic tools will include a gnomon and a small workbench with a fold-down seat, both stowed in the aft section. Devices to be carried will be determined in close consultation with the Australian planetary science community, including geologist Professor Malcolm Walter at Macquarie University and geophysicist Dr Nick Hoffman in Melbourne.

2.4.5 Vehicle Control

Vehicle indication systems will be located in front of the side by side driving seats (similar to a light aircraft). Although interfaces such as a head up display (HUD), touchscreens and voice activation would be highly desirable and possible inclusions in a real Mars rover, Marsupial will initially specify the cheapest, most practical and functional COTS analog dial and digital gauges. However, a primary multipurpose vehicle computer, probably located in this nose section, is regarded as essential. Steering and acceleration will be via an omni-directional joystick. A secondary joystick may be retrofitted near the egress door to allow backwards mating with a hab door, and control of a future RMA via a toggle switch.

A key feature of Marsupial is tank-like differential steering. The use of independent electric motors on each wheel allows development of a custom computerised control system/human interface and neural network algorithm for optimising turning and ground traction. This system is expected to represent a major contribution to the engineering objectives of the project.

With the basic platform operational, retrofitting of a telerobotic control system is planned, with short range control of Marsupial by an EVA crewmember, and longer range control with video and data feedback from base. This will contribute to simulations by testing the functionality and value of remote control for productive surface exploration.

3. Performance Requirements

3.1 Speed

See 2.2.4.

3.2 Range

As required, the vehicle round trip range will be 320 km with a total Marsupial payload of 1,500 kg.

3.3 Vehicle Mass

Wombat is the largest possible vehicle of its kind (cabin shape and wheel configuration) that can pack within the specified C-130 envelope. As such it gives us a starting point from which to work backwards to refine a smaller, more appropriate design.

Final mass for the Wombat variant is highly dependent on materials selection. With the use of carbon fibre, high strength alloys and aluminium for the cabin, the dry weight will be in the range 1,500 – 2,000 kg. With materials that we may be forced to use in practice, this figure could reach 2,750 kg. Further detailing of Wombat will produce a definitive figure.

Although Wombat gives us a clear picture of the geometric boundaries within which we can work, its mass is excessive and the smaller variant will focus on system mass, a critical mission-enabling factor. Discipline in adhering to the specified budget of 1,500 kg is an essential part of achieving our engineering objective. The smaller variant will not exceed 1,500 kg dry weight.

3.4 Terrain

Marsupial has been designed as a high performance AT vehicle, with superior performance through rocky terrain. A sophisticated wheel motor control system with learning capability will ensure optimal traction on rock, soft sand and ice and reduce the chance of bogging. Tipping is unlikely with the large wheel footprint.

3.5 Logistics

The Wombat variant has been designed to fit within the specified packing envelope, and the smaller variant to be built may be smaller than this envelope. For Australian desert campaigns, Marsupial will be towed on a trailer by a 4WD vehicle. Incorporation of variable ride height will allow the vehicle to be driven over the trailer and lowered by activation of the VPD system, whereupon it will be secured via hardpoints on the exoskeleton. A custom trailer will not be needed.

Detail design of essential (or "1st tier") Marsupial structures will be a nationally and internationally co-ordinated effort managed from Brisbane, Queensland, Australia, over a 6-12 month period. We will develop documentation and procedures that comply with the ISO 9001:2000 quality system (easily adapted from another MSA project, ALUMINATE, the Australian Lunar-Mars Investigation and Technical Evaluation managed by the Australian Space Research Institute (ASRI)[12]).

Integration of all systems will also occur in Brisbane. Ideally, an engineer will be employed on a full or half-price contract basis by MSA for a 6-month period to manage fabrication, acquisition and assembly of components and final integration and testing of the basic platform. Engagement of an experienced engineer undertaking a full time Masters Degree (in, say, Technology Management) would be another desirable option. They will be accountable to a project committee of 3-6 members involved in detailed design and outreach activities. MSA is currently acting to establish the organisational and legal frameworks necessary to conduct commercial relationships for the project.

Detailed design of more complex, and in some cases non-essential "2nd tier" Marsupial systems will require 12-36 months. This is because a significant portion of this work will be carried out as university undergraduate and postgraduate projects, and we are at the mercy of the academic semester cycle. While this represents a constraint in development of a project timeline, the use of coursework students provides considerable free manhours for valuable research, system design and simulation, and final fabrication using university workshop and computing facilities.

For this green fields project, testing and commissioning of the basic platform will require 3-6 months following final integration, although university coursework subsystems will be fitted and tested over a longer period. When all essential systems have been fitted and individually commissioned, the first 2 week operational campaign is likely to be undertaken in the Woomera Restricted Area in South Australia, where MSA will work closely with ASRI (http://www.asri.org.au), an organisation experienced with the regulatory and logistical issues of mounting rocketry campaigns in the range. By this time, we hope that an international Mars Simulation Facility will have been established.

Antarctic or sub-Antarctic deployment could be via an Australian Government resupply vessel and/or aircraft drops. Ship transport is likely to be cheapest and most feasible. We will pursue the possibility of securing half a shipping container on either the RSV Aurora Australis or MV Polar Bird[13] and the smaller Marsupial variant will be designed from the start not only to conform to the C-130 envelope specified for this competition, but also to the standard container dimension for these resupply vessels (likely to be smaller in cross section). Marsupial will be folded and wheeled into the container on a custom trolley, secured at four or more points, with additional supplies and equipment needed by the campaign crew packed around the vehicle. Crewmembers could be flown in or would travel by ship to the chosen site.

Davis Station (68°35'S, 77°58'E) is a promising Mars analog site, located on the edge of the Vestfold Hills, an ice-free area of about 400 square kilometres. It is bare, low-lying hilly country deeply indented by sea-inlets and studded with lakes and tarns of varying salinity. Numerous islands fringe the coast up to 5 kilometres offshore. It is the largest coastal ice-free area in Antarctica.

Such a campaign will be a major logistical exercise probably requiring extended negotiations with Australian government authorities, but would offer international members of the Mars Society access to an additional site complementing the U.S. McMurdo Dry Valleys.

We look forward to working with groups such as ThinkMars[14] to develop and adapt strategies for winning the resource support needed to build and operate Marsupial, and further to establish an Australian Mars Simulation Facility (AMSF).

3.6 Crew

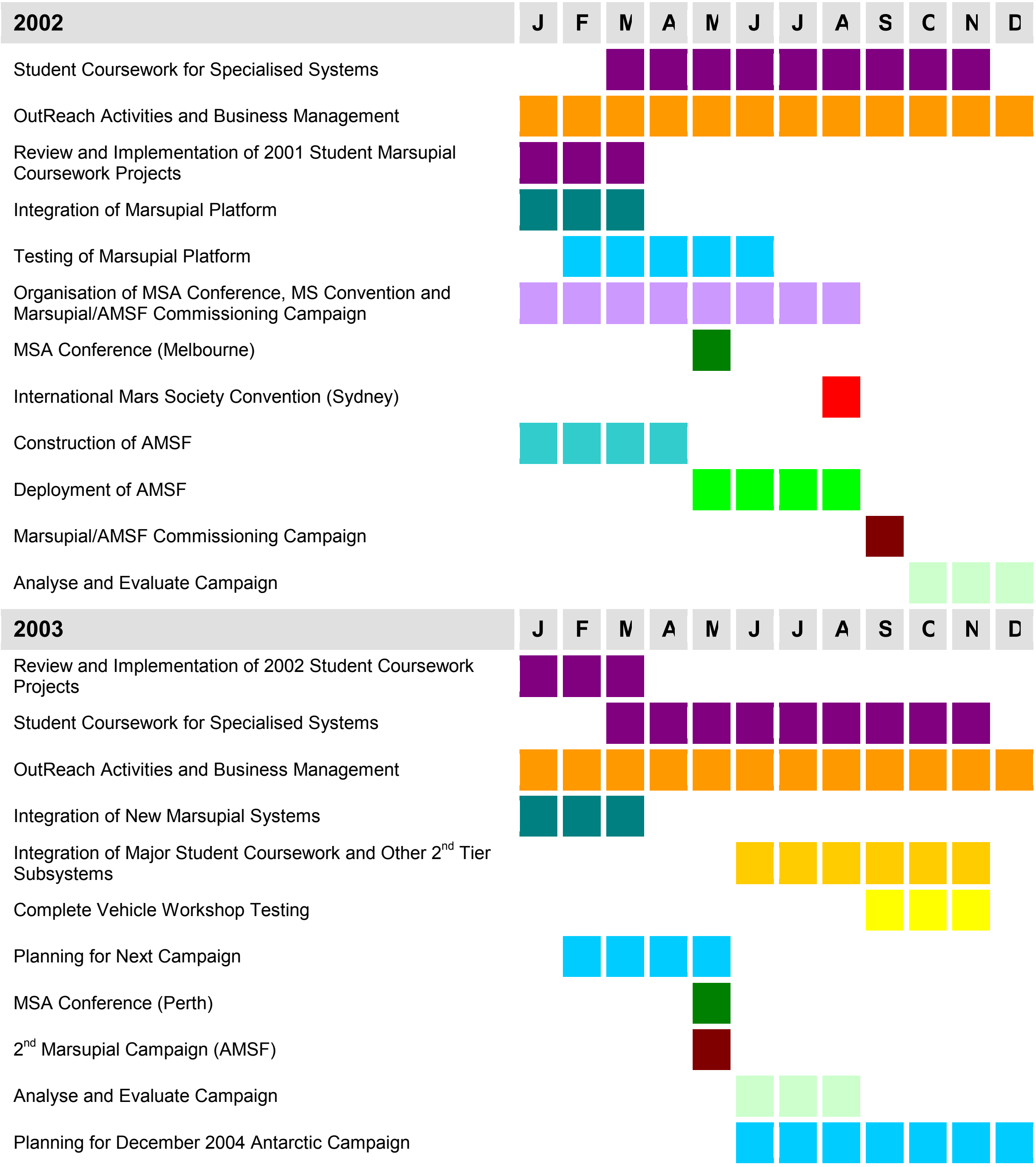
It is expected the Wombat variant will accommodate a crew of 4 in relative comfort. The smaller variant will be designed exclusively for 2 with emergency accommodation for 4, reducing mass wherever possible.

Typical dimensions for a standard human have been used in the current concept design (e.g. 1.8 m tall, shown in drawings), and close reference will be made to the U.S. Department of Defence Human Engineering Standard MIL-STD-1472F[15] during detailed design.

4. Schedule

The selection of a range of systems on Marsupial requires identification of additional constraints. Therefore a 3-month Project Definition Study (PDS) will be undertaken as the first stage of detailed design. This will freeze all specifications and generate a systems level Work Breakdown Structure (WBS). A preliminary timeline follows for the design, construction and operation of Marsupial. It shows how development of an Australian Mars Simulation Facility could be undertaken in parallel (where significant involvement from international Mars Society members is assumed). It may be desirable to stage development of Marsupial with an interim modified substitute, in which case as much as 12-36 months may be added to the schedule for the custom Marsupial variant.

Activity												
2000	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
Commence Detailed Design of Base Platform									■	■	■	■
Establish International Alliances								■	■	■	■	
Establish National Partnerships and Develop Academic Network								■	■	■	■	■
Develop Project Management Systems									■	■	■	
Mobilise and Recruit (general)										■	■	■
Develop Business Plan, OutReach Material									■	■	■	■
Planning for Australian Mars Simulation Facility (AMSF)									■	■	■	■
2001	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
Student Coursework for Specialised Marsupial Systems			■	■	■	■	■	■	■	■	■	
Detailed Design of Base Marsupial Platform	■	■	■	■	■	■	■	■				
Prepare for Marsupial Construction Stage					■	■	■	■				
Order and Delivery of Marsupial Long Lead Items							■	■	■			
Commence Marsupial Fabrication									■	■	■	■
Commence Marsupial Integration											■	■
Commence Marsupial OutReach Activities and Sponsorship Plans	■	■	■	■	■	■	■	■	■	■	■	■
Detailed Planning for AMSF	■	■	■	■	■	■	■					
Site Selection and Tendering for AMSF								■	■	■	■	■
MSA Conference (Brisbane)					■							
Organisation of 2002 MSA Conference, MS Convention and Marsupial Commissioning Campaign						■	■	■	■	■	■	■



4.1 Sponsorship

Consider if project Marsupial were undertaken on a purely commercial basis…

To date around 300 manhours have been expended on conceptual design, which at an average of AUD$50 (US$28.9) per hour, equates to AUD$15,000 (US$8,689). Detailed design may require approximately four full time engineers (one each for structures, power and drive, special systems and operations) and two full time draughtsman for a period of 6 months. In practice this would of course be spread amongst many pro bono professionals, students and MS volunteers. With one experienced automotive engineer at say AUD$80,000 (US$46,344) per annum, three graduates and two draughtsman at AUD$50,000 (US$28,965) pa, production of a complete detailed design ready for fabrication and with a high level of confidence in vehicle performance, will cost approximately AUD$165,000 (US$95,585). This figure assumes all tools and facilities for the design team are inclusive, and hence is conservative.

Ideally, materials such as aluminium alloys, carbon fibre composites, and high performance, high reliability components would be used to maximise vehicle performance and functionality within the mass budget of 1,500 kg. In this case, we can expect the cost of materials, labour and components for construction and assembly of the fully equipped Marsupial to reach around AUD$200,000 (US$116,000). If significant compromises are made on either weight and/or functionality and performance with the use of substitute materials and components, the cost of the bare platform might be brought down to AUD$80,000 (US$46,000).

The total cost might therefore range from around AUD$245,000 (US$142,000) to AUD$365,000 (US$211,000) on purely commercial grounds.

In practice we will call on the services of an army of volunteers and develop a Business Plan to identify clearly and concisely ways that a range of organisations and individuals can benefit from involvement. A key strategy is participation of a major international television crew (e.g. Discovery Channel, NHK of Japan) to document the construction and commissioning process.

With entirely volunteer design work and construction/assembly on a partly commercial basis, we estimate the ideal, high performance, basic Marsupial simulation platform can be operational by the first quarter of 2002 for less than AUD$150,000 (US$87,000). We suggest the following possible sources of funding:

Source	2000	2001	2002	2003
Mars Society	AUD$30,000	AUD$20,000	AUD$10,000	
Universities		AUD$10,000	AUD$10,000	AUD$10,000
Government		AUD$10,000	AUD$10,000	
Multinational Corp		AUD$10,000	AUD$20,000	AUD$20,000
Local Corporate		AUD$10,000	AUD$10,000	AUD$10,000
Private Donations			AUD$5,000	AUD$5,000
Subtotal	AUD$30,000	AUD$60,000	AUD$65,000	AUD$45,000

This calls for a contribution from the international Mars Society of AUD$60,000 (US$34,758), comprising a cash seed payment of AUD$30,000 (US$17,379) and contribution of major vehicle components in 2001 and 2002 to the value of AUD$20,000 (US$11,586) and AUD$10,000 (US$5,793) respectively.

It is conceivable that a University may adopt the project and contribute AUD$30,000 over a 3 year period, perhaps with involvement of its commercialisation arm. The government funding includes a Queensland State and a

Federal component, and a number of grant avenues exist, including educational (State), science & technology awareness (Federal) and small enterprise collaborative R&D (State and Federal).

Seed funding is critical to attracting further sponsorship, not least from a small number of multinational corporations and local Australian business. We will not rely on private donations, although these can be expected as the profile of the project increases.

In parallel with these sponsorship and grant efforts, we will approach various organisations with essential manufacturing capabilities, seeking donated labour and use of facilities. This will initially focus on potential vehicle structure suppliers, such as aluminium welding shops, and fibre composite and alloy casting centres.

5. Discussion and Conclusion

Marsupial is a project that MSA wants and one that Australia needs.

Some of the key benefits of the project:

- It will open the eyes of people around the world to space activity for which you don't need a rocket, making the concept of a human Mars mission much more real, accessible, and desirable,

- It will make Australians at the public, academic, corporate and political levels aware and proud that our country can make a real, significant and recognised contribution to international space activity,

- It will form part of a strategy to encourage an Australian national space programme and ensure that it will adopt a balanced focus not restricted to earth observation and including planetary exploration as an objective, and

- It will provide us with a platform to fulfil valuable Mars Society simulation objectives in the most realistic way possible,

We acknowledge inherent tension between advocates of simulations performed at low cost with a focus on human factors research, and those seeking to also encourage technological development and the involvement of Australians in the design of future Mars mission hardware. These positions needn't be mutually exclusive.

It must be recognised that there is a dearth of research work on human operations simulations for Mars. There has been no government or commercial imperative for expenditure on Mars human simulation work. In contrast, there has been much theoretical work in academia and the various space agencies (mainly within NASA since the Apollo programme), on hardware design for such missions. Interestingly it is the human factors that should dictate this technological work. Even so little actual analog hardware has been built.

The Mars Society will increasingly undertake private development of simulation facilities around the world, making a major contribution to simulating, scientifically observing and learning from Mars analog operations.

We believe that only a custom platform solution (such as the Devon Island habitat structure) for the pressurised rover can properly capture the imagination of the public and global attention needed to take us a step closer to a human Mars mission. It is more challenging, yes. It is technically more difficult, yes. The material and human resource hurdles are at least an order of magnitude higher, yes. But only a custom vehicle can properly mobilise the interest and involvement of a wider range of major organisations and individuals. To draw out this interest, we must be ambitious. The effort is not misdirected, for there is no reason why we cannot also build rough-and-ready substitutes on the road to Marsupial.

Wombat is the first concept in a series of vehicle designs. We wish to build a smaller variant. MSA may also acquire a second hand 4WD van such as a Mitsubishi Star Wagon and modify it to meet Marsupial specifications as an interim measure. While this will require as much as AUD$40,000, the support of one of the many recreational vehicle modification workshops in any of Australia's main capital cities, and may be a useful first task to help mobilise MSA volunteers across the country, scope for corporate, academic and government support is far more limited. It also distracts resources and extends the project timeline, yet we acknowledge all of this may be necessary to reach our final goals.

Marsupial is a perfect complement to our countries fledgling involvement in spacecraft systems (through companies such as Auspace Ltd[16] supplying components to the world), small-scale satellite projects (such as the 58 kg Fedsat-1[17]), launch vehicle proposals (including the indigenous AUSROC-III and IV liquid rockets planned by ASRI, and the commercial proposals of United Launch Systems International, ULSI[18] (base planned at Gladstone, Queensland), Asia Pacific Space Centre, APSC[19] (based planned at Christmas Island, off Indonesia), Kistler Aerospace[20] and Spacelift[21], both planning to launch from Woomera) and feasibility studies for ambitious national activities (such as Aluminate[22]).

All of these are focussed on launching objects skywards, but there is another way Australia can get into space – by building an expertise in systems that will increasingly be used on the surfaces of other planets. Some Australian strengths include:

5.1 Mining

We could apply our specialist skills and technology in minerals exploration, and surface and underground mining to an activity that may form one of the first commercial drivers for more aggressive interplanetary space activity, mining for industrial applications on Earth or in low earth orbit (LEO), and for In Situ Resource Utilisation (ISRU), seen as critical to facilitating human colonisation of Mars.

5.2 Astronomy

Australia boasts world leading facilities and personnel in this area[23], with major optical[24] and radio[25] observatories. Observations are however hindered by Earth's thick atmosphere, and Australia can make a valuable contribution to the construction and operation of future facilities on other planetary bodies or in space.

5.3 Remote Sensing

Australia is a unique vast island continent and furthermore, one that relies heavily on natural resources for national wealth. We are becoming increasingly dependent on satellite observation platforms and have developed an expertise in spectral imaging and analysis for mining, agriculture and natural resource management. In the same way remote sensing is proving its value for us on Earth, this expertise will be especially useful for exploration and scientific characterisation of Mars.

5.4 Automotive

To this we might add automotive land and air technology. Australia is vast and mobility is a national imperative. Although we have in recent decades become dependent on imported cars and aircraft, an interest and expertise in automotive design and construction remains. Australia hosts the internationally renowned World Solar Car Challenge and we have links with successful teams such as those at the University of Queensland and the University of New South Wales.

Marsupial is ambitious not simply to attract attention – its design and construction is eminently achievable and there are a range of groups who would benefit from an association with the project.

The Federal Government, the CSIRO and dozens of Australian industrial partners have been involved in the development of the low emission aXcess Australia car[26]. Australia is one of the few countries in the world that can build a motor vehicle, particularly an electric hybrid, from the ground up. The aXcess vehicle employs special super capacitors for transient power boost, developed at CSRIO.

In addition to this, the Australian Army has special All Terrain vehicle needs and works with local companies such as ADI Ltd[27] and Tenix Group[28] to develop custom solutions such as the Bushranger[29] wheeled armoured personnel carrier. Through the Institution of Engineers, Australia (IEAust) and the Society of Automotive Engineers (SAE), we can access an extensive network of automotive consultants who will be engaged in Marsupial detailed design, many of them based in Melbourne.

Marsupial may be designed for another world, but it can showcase specialised products of local and international ingenuity.

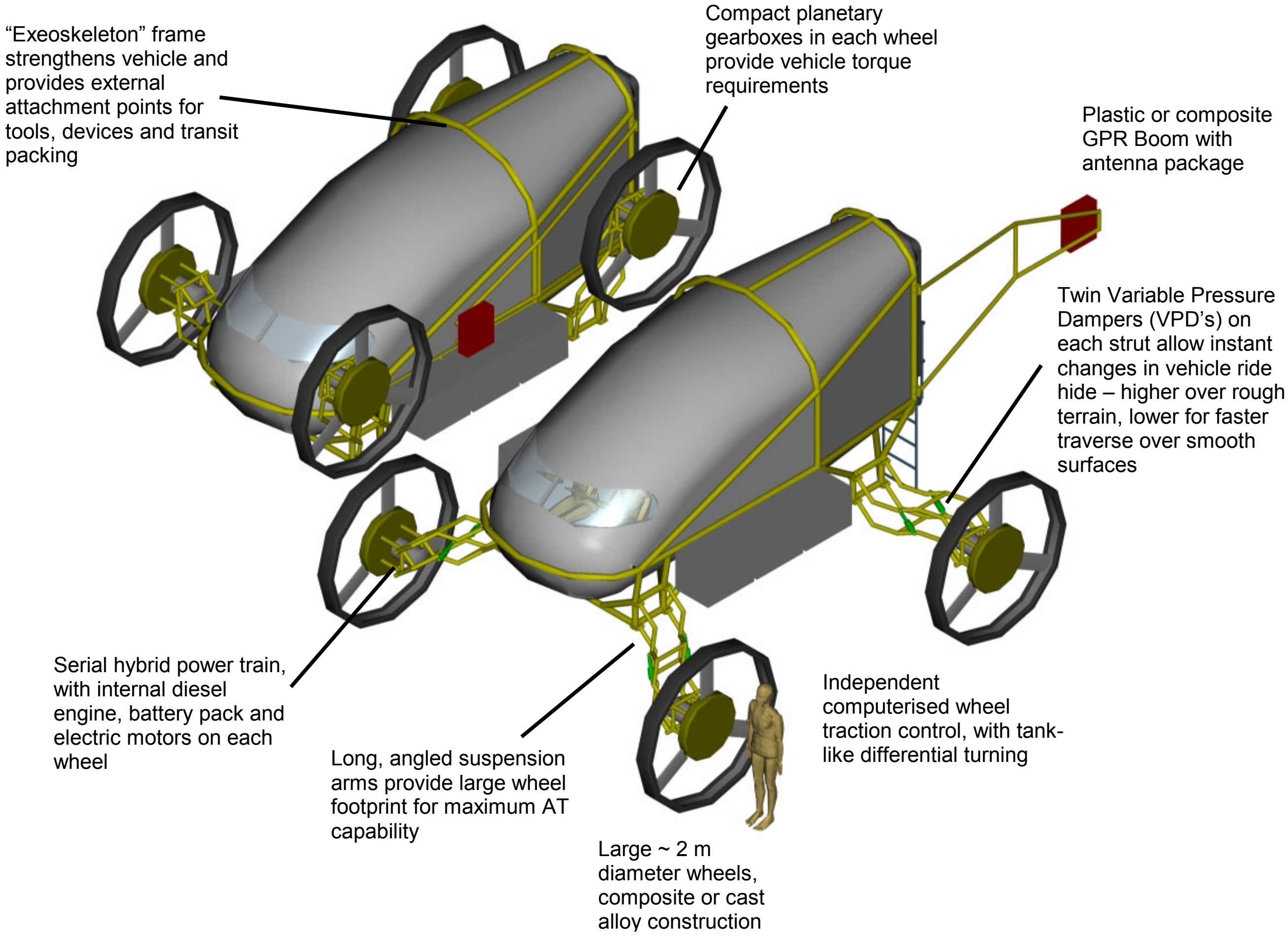
Our goal is to bring together these various strands of industrial expertise with the academic community, and involving Mars Society members wherever possible, to build a unique Mars rover simulation platform. We know that this will not be easy[30]. Yet we are confident of attracting interest, and most importantly support of the kind that will help us to actually build the vehicle.

Marsupial will be a highly effective marketing tool for encouraging a more ambitious national space programme, one that needn't be exclusively focussed on a vertically integrated launch and space operations capability. Niche planetary surface technologies are accessible (we can build and operate analogs in our backyard), can generally be equally well used for terrestrial purposes (e.g. Marsupial could fitted with specialised laboratory equipment and used by biologists seeking new species of flora and fauna, to undertake week long sorties in Australian desert locations where standard 4WD vehicles may be less functional), require R&D work which can result in world leading technologies and export income (the spin-off argument) and, just as importantly, can be wheeled out at museums, shopping centres, schools and other places where the Mars Society can spread its message to the public in between operational campaigns.

Marsupial will contribute to the Mars Society goal of private activity bringing us closer to a human Mars mission opening the way for development and colonisation of the Red Planet. It will also contribute to the MSA objective of encouraging a far greater role for Australia in space activity.

The challenges of building this vehicle pale into insignificance when we consider the barriers we, members and friends of the Mars Society here and around the world, face in working to send people to Mars and establish a new branch of civilisation. In this we choose to face the seemingly impossible, let us now choose to build Marsupial and take an important step closer to making it happen.

6. Views of Marsupial variant *Wombat*



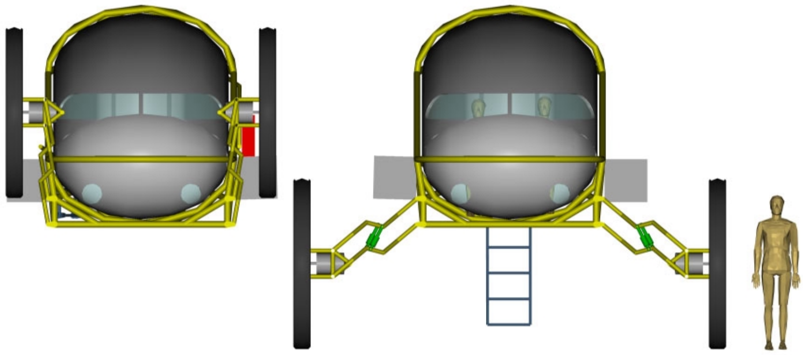


Figure 4 FRONT VIEW

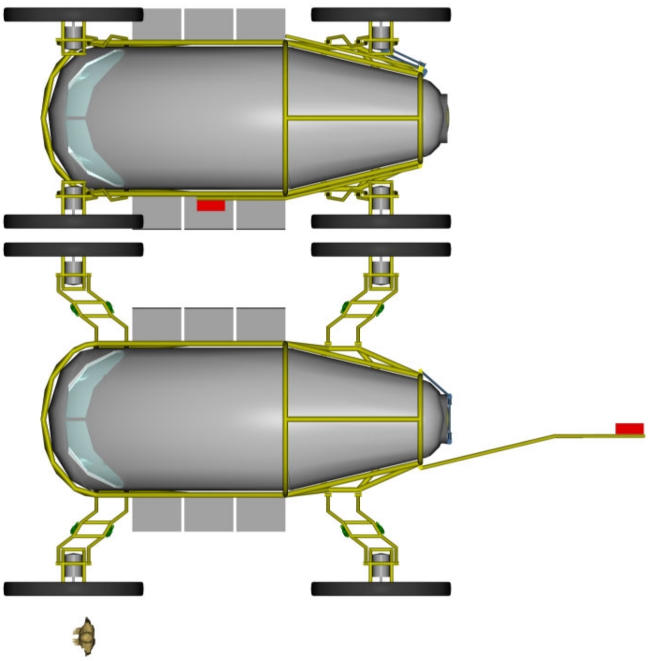


Figure 5 TOP VIEW

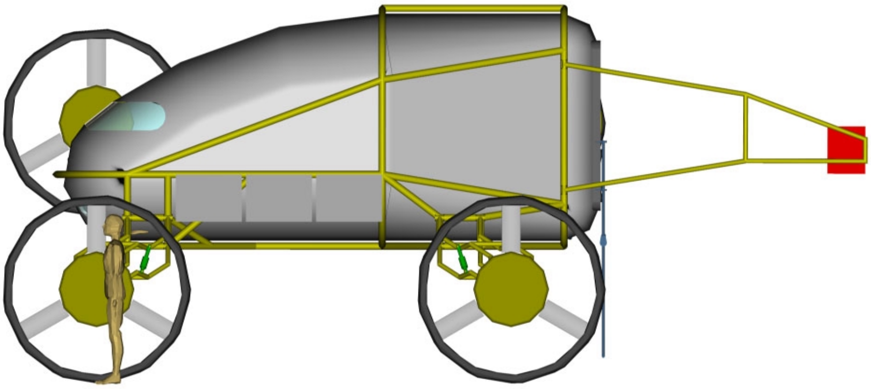


Figure 6 SIDE VIEW

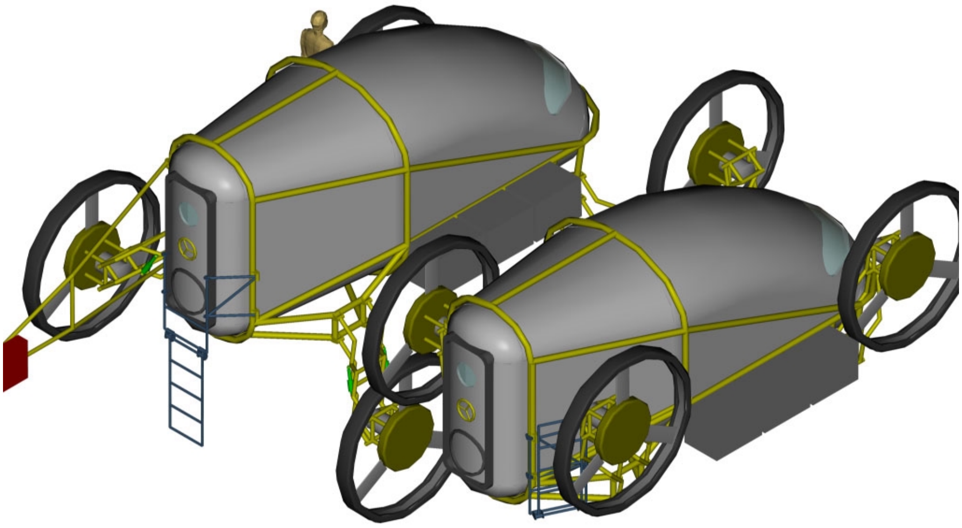


Figure 7 REAR ISOMETRIC VIEW

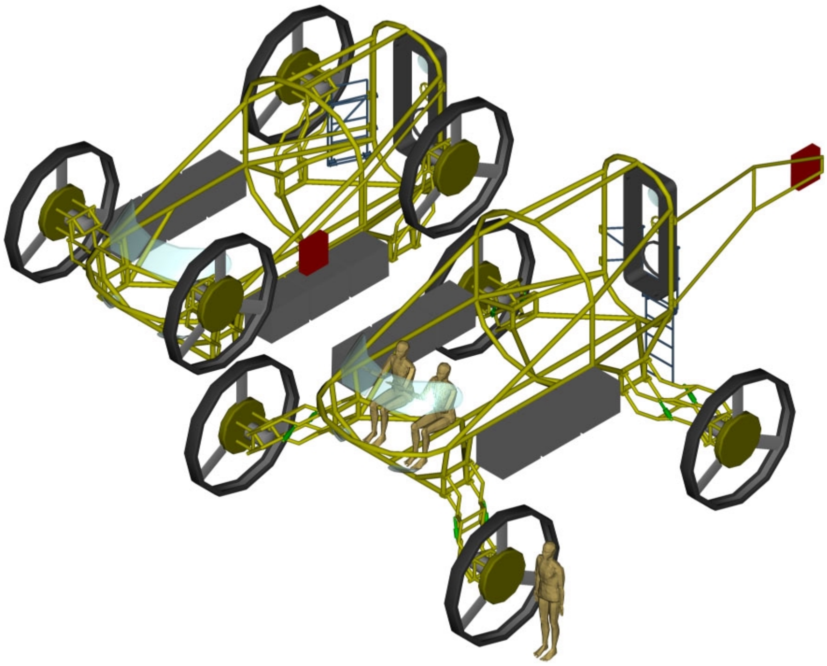


Figure 8 FRONT ISOMETRIC VIEW, with cabin structure removed

7. References and Notes

[1] An Australian marsupial.
[2] Smith, P.H., et al, First results from the Pathfinder camera, *Science*, 278, 1758-1765, 1997.
[3] Calculations based on notes from Wright, D., *Design and Analysis of Machine Elements*,Department of Mechanical & Materials Engineering, The University of Western Australia, Feb 1995.
[4] http://www.mech.uwa.edu.au/study_here/staff/staff.html
[5] http://www.ctts.nrel.gov/analysis/
[6] http://quasiturbine.promci.qc.ca/QTIndex.html
[7] e.g. see http://ee.unsw.edu.au/~p2139851/alten-au.html
[8] e.g. the Australian Cooperative Research Centre for Renewable Technology, ACRE, http://acre.murdoch.edu.au/acreintro.htm and the Commonwealth Scientific and Industrial Research Organisation, CSIRO, http://www.csiro.au/
[9] Ceramic Fuel Cells Limited (http://www.cfcl.com.au/)
[10] http://www.cssip.elec.uq.edu.au/home.html
[11] NASA STD-3000B
[12] http://www.asri.org.au
[13] http://www.antdiv.gov.au/southbound/index.html
[14] http://www.thinkmars.net/thinkmars2.html
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[25] http://www.atnf.csiro.au/
[26] http://www.axcessaustralia.com/default.asp
[27] http://www.adi-limited.com.au/
[28] http://www.tenix.com/home2.html
[29] http://4wd.sofcom.com/Mil/Aus/Bushranger.html
[30] In spite of the development of a Business Plan, we know that nationalism will be one of our most effective motivating factors.