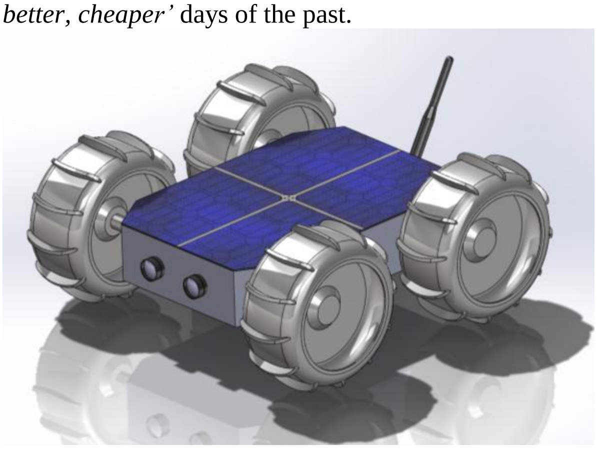
**SMALER – Small Mobile Agile Lightweight Exploration Rover –** M. Frost[1] and C. McQuin[2]. [1]Jet Propulsion Laboratory, California Institute of Technology, mfrost@jpl.nasa.gov [2]Jet Propulsion Laboratory, California Institute of Technology, cmquin@jpl.nasa.gov

***Mars Surface System Capabilities - Near term***

**Introduction:** The technical challenges of rover design are strenuous, but in these uncertain economic times a major impediment to success comes not from engineering but from the budget. Either the cost is too high to begin with, or the project is cancelled due to fluctuating commitments. A small, lightweight, low-cost, build to print rover thus would have wide appeal as a way to push exploration forward and also honor the *'faster, better, cheaper'* days of the past.



A rover such as this would be useful in many applications:

(1) a scout for fertile grounds for a sample return mission;
(2) tacked on to an existing static lander mission, to explore *just over the horizon* or bring objects of interest to the landers' instruments;
(3) as part of a multiple rover scattering, increasing the chances of reaching a specific science target (known as the shotgun approach or not putting all your eggs in one basket);
(4) or simply used to get more *eyes on the ground*. Who knows what we could discover?

The costs associated with building more traditional rovers are heavily front loaded in the design, verification and validation; because the simplicity of the SMALER strategy, those costs can be kept low. A flight validation mission could be obtained by tagging on to an existing lander mission, similar in spirit to the original *Sojourner*.

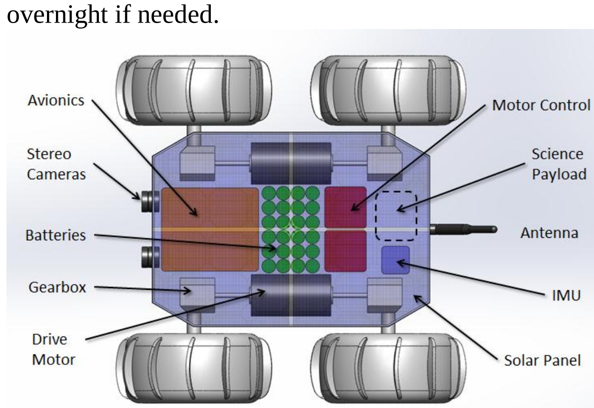
**Concept and Design:** We propose to design and build a low-cost rover taking some cues from designs in the RC (remote controlled) hobby industry. We intend to take those ideas that are beneficial to Mars rovers and adapt them to flight.

*Design Overview:* The basic principle is to use extreme simplicity to keep costs low while still maintaining the ability to meet the primary objective of roving Mars.

The size of the rover would be between *Nanorover* and *Sojourner*, targeting a mass of under 10kg. The rover would be equipped with standard equipment: warm electronics box (WEB), drive actuators, avionics, inertia measurement unit (IMU), batteries, solar panel, UHF radio, and space for a small science payload. It would be designed with a targeted build to print cost of $5M per additional rover.

4-wheel drive toy cars generally use a single motor to drive the four wheels and an additional actuator to control steering on the front wheels. There are flaws to this approach: exposed steering mechanism, inability to turn in place, and a differential drive that can allow one wheel to slip and spin while the other stays put. A more robust method is to use the two drive actuators in a skid steering design. This removes all of the negative aspects of toy car design stated above, but keeps the positive low actuator count and improves robustness.

*Benefits:* While the design requires only two actuators to perform its primary objective of roving, importantly both actuators could be easily housed inside the WEB. By housing the actuators in the WEB, their temperatures could be maintained without the need for additional heaters. An added benefit is that the actuators themselves could be used as heaters by energizing windings to help keep other sensitive electronics warm overnight if needed.




Because the rover would use two actuators (a typical rocker bogie based rover uses 10 for mobility), these drive actuators would be oversized to increase both speed and torque, which have numerous benefits as detailed below.

High centering a rover on a rock or obstacle could mean end of mission for any rover. Wheels on the

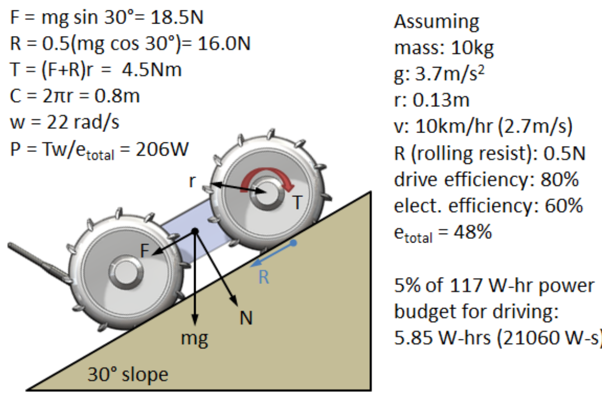
SMALER design would be placed close together to help avoid this situation. But in the case of a high center condition, all is not lost. Rovers that utilize high speed/torque motors could employ a special maneuver for extraction. By running the drive motors to full speed, then quickly stopping them, reaction forces from the abrupt stop could cause the rover to shift and slide off the high center. This maneuver could also be used to impart moments on the rover and twist it off as well. With a conventional rover the wheel speed is far too slow to impart forces on the chassis large enough to slip it off a rock.

Another useful benefit of a high speed/torque motor is that in sandy conditions where a conventional rover may get stuck, the high speed actuator could create a sand swimming case. If the wheels are spun quickly enough the grousers could act as paddle wheels and the thrust imparted from the flying sand could propel the rover forward and out to safety. Shown below is an RC vehicle executing a similar maneuver:

*Power:* At the start of mission the MER rovers solar panels could generate ~650 W-hrs/$m^2$ per sol.[1] A SMALER design could easily be constructed with solar panels >0.18 $m^2$, thus generating ~117 W-hrs per sol. This is a tight power budget, but not impossible. The key is to use survivable electronics, ones that could survive near the -110C° temperatures of a Martian night. These electronics do not need to operate at such extremes. Operations are suspended until surface temperatures are warm enough to operate. In low temperature cases the motors could also act as low wattage heaters to help maintain survivable temperatures at night or speed up the heating of components in the WEB for a morning drive.

The motors themselves would be thermally isolated from the robot's externals by design so that much of the heat generated could be kept in the WEB. Connections from the WEB to the outside would be kept to a minimum (cameras, antenna, drive axles) to ensure low heat loss through gaps and conduction.

*Performance:* A back of the envelope performance calculation is shown below. Assume that driving is allotted 5% of the total 117W-hr daily power budget. The rolling resistance is simplified to 50% of the normal force, while using a rover mass of 10kg and speed of 2.7m/s.




Can drive 276 meters up a 30° slope in 102 seconds once per day

This represents big performance from a little rover.

*Operations:* A small area would be reserved for science payloads, such as a gas sensor or microscope in addition to the cameras on the front of the vehicle. The rover would plot a course to its science objectives and dead reckon to the destination using IMU data. It is likely that after a drive, course corrections would be required until the rover is close to its destination. Tracking shadows from the antenna or a sun tracker could be used to re-calibrate the IMU.

Due to low power generation of the solar panels and the speed torque curves of RC car-like motors (greater efficiencies are achieved at higher speeds), a more aggressive drive over a short duration is encouraged. It is easy to imagine how driving in this style the rover may be prone to flip. Thus solar panel would be installed on both sides. This could enable the rover to drive upside down. High centering on rocks and getting stuck in soft sand would be handled as previously mentioned. The robust design is similar in temperament to that of an RC car. It could drive aggressively off almost anything and survive.

**Conclusion:** A simplified rover design could offer a robust mobility platform with significantly reduced cost, thus enabling tag-along missions, scouting missions, or multiple rover missions. This type of architecture could also spur advancement as innovators focus on new and exciting instruments that could fit in the standardized payload box, similar to the instrument revolution currently happening with CubeSats.

**References:**

[1]http://pdsimg.jpl.nasa.gov/Atlas/MER/documents/insthost.cat