

TerraBuilder's

# Apollo LRV

Lunar Roving Vehicle Simulator

Electric-powered, 2-man lunar surface vehicle simulator  
For Flight Simulator 2004 only - TerraBuilder: Moon Add-On Required

## Operating Manual

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by Ron Creel, Member of the Apollo LRV Team

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The TerraBuilder Team wishes to express appreciation and gratitude to the following individuals, without whom this project would have lacked the detail and authenticity we strived to deliver:

**Ron Creel**, Member of the Apollo LRV Team, for his expert technical input and advice and insight on intricacies and inner workings of Apollo's amazing Lunar Roving Vehicle.

**Eric Jones**, of the Apollo Lunar Surface Journal, for creating and maintaining a treasure trove of Apollo-related information, documentation and media.

**Don McMillan**, for his incredible Apollo Lunar Rover poster, which was a source and a "detail check" for all the small parts not covered in the available NASA blueprints and technical manuals.

# INTRODUCTION

TerraBuilder's Apollo Lunar Roving Vehicle (LRV) add-on for TerraBuilder: Moon presents to date the most detailed and authentic software-based simulator of the first and only vehicle humans drove on another world. TerraBuilder's rover started as a simple driving buggy intended to amuse the author by bouncing across TerraBuilder's bumpy lunar terrain. After a few trials and experiments, the performance was tweaked to as close to the NASA specifications as possible, within the confines of FS system. Then, the visual model was upgraded and the rover took on a more realistic feel. Finally, realistic features (such as thermal model) were added, to augment the feel for the operational procedures astronauts went through while using the LRV on the moon.

While most of the navigational and display parameters are modeled, the simulation does not model power distribution and management - this is simply outside its scope. As such, all of the switches on the bottom part of the control panel are inactive. Also, there are a few user adjustable animated parts on the rover: The high and low gain antennas can be adjusted, however, this is purely for the visual appeal - it does not, in fact, have any effect on the simulation, other than giving driver a better view ahead.

Likewise, the animated fender extensions, astronaut's visor segments and the tool rack simply illustrate the movable parts of the rover and the astronaut gear. Other animations, in particular, the steering and suspension linkage and the battery radiator covers, are accurately portrayed and represent actual workings of the LRV mechanical systems. Other simulation features are:

TV cam, LCRU and battery dust covers covered in real-time rendered reflective mylar KAPTON material.

Instrumentation functionality: Console contains a fully functional instrumentation including: Heading, distance, bearing and range displays, Nav Reset switch, Fully functional overheat warning flag, gauge monitors for Ampere-Hours, Volt/Amperes, Battery and Motor temperatures with Battery 1,2 and Motor F/B selector switches.

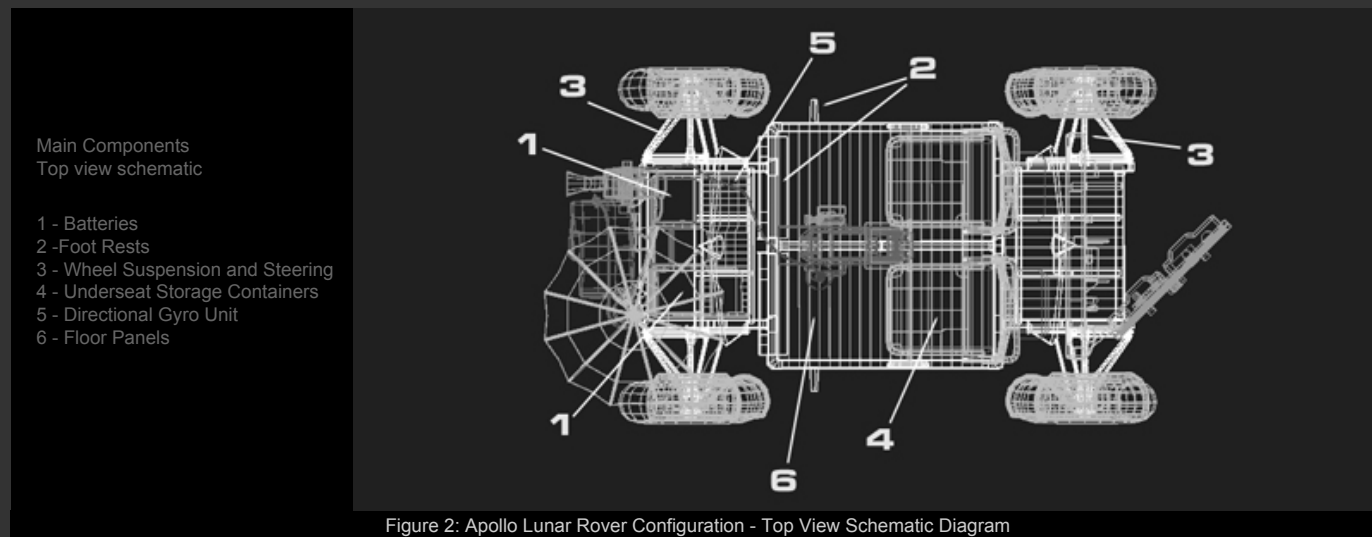
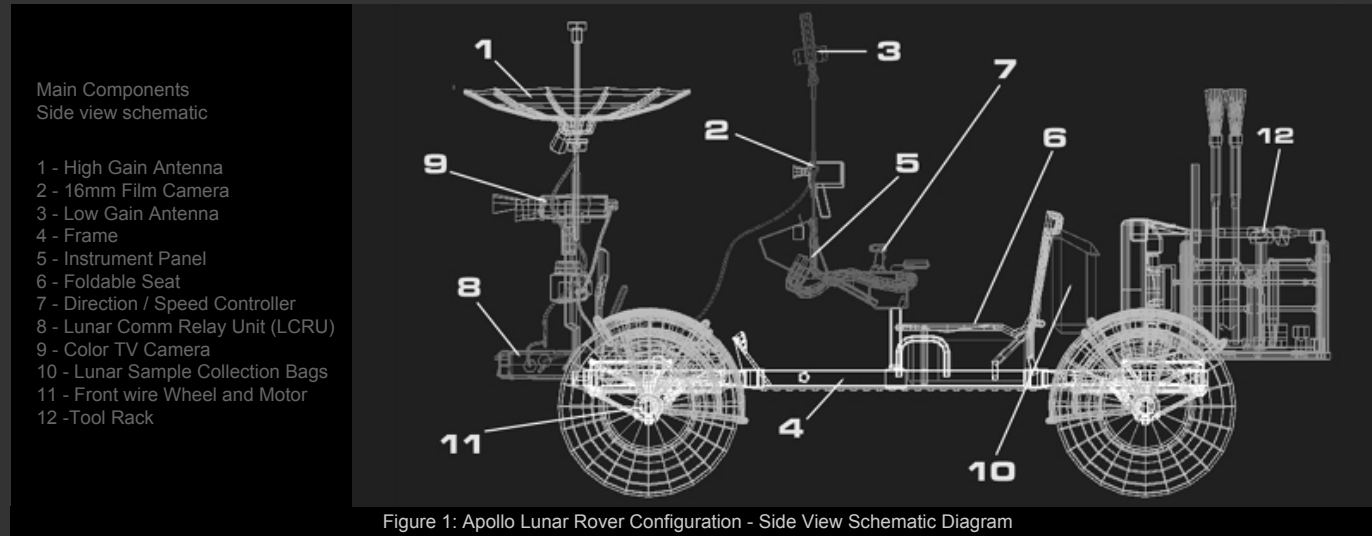
The batteries actually heat up, and when they hit 125F, the warning flag flips up (can be user re-set). You can cool off the batteries by opening the radiator covers.

The motors heat up as well - warning flag pops up when the upper limit is reached. They can be cooled off by parking the rover for a while.



## VEHICLE CONFIGURATION

The aluminum chassis is divided into three sections that support all equipment and systems. The forward and aft sections fold over the centre one for stowage in the LM. The forward section holds both batteries, part of the navigation system, and electronics gear for the traction drive and steering systems. The centre section holds the crew station with its two seats, control and display console; and hand controller. The floor of beaded aluminum panels is capable of supporting the weight of both astronauts standing in lunar gravity. The aft section held the scientific payload and tool rack.



## VEHICLE OPERATION

### STARTUP AND SHUTDOWN

LRV's mobility system is activated by FS's auto engine startup sequence (CTRL-E by default) and shut down sequence (CTRL-SHIFT-E by default). There are no audible or visual cues to this event, except for a slight delayed "nudge" when the system is activated (this is the effect of FS's starter torque).

### SPEED CONTROL

Speed of the rover is controlled by the amount of thrust. You can set thrust level using the default FS thrust controls, but it is highly recommended that a high quality joystick be used as a controller device. The best (and closest to the real LRV controller) is the type with the twistable handle that controls Z axis ( rudder, or yaw ) and a built-in thrust slider. Although the rover was capable of it, the simulator does not support the reverse motion - this is the limitation of Flight Simulator. The astronauts indicated that reverse driving was only used on very rare occasions - they would actually pick up the LRV if they needed to.

### BRAKING

Braking is activated using the default Flight Simulator braking key ( "." by default, or a joystick "fire" button). Parking brakes are also set using the Flight simulator default key ("CTRL + ." by default), however, "BRAKE" label visible in the lower right portion of the screen has been disabled because another TerraBuilder vehicle, MoonHopper, has the parking brake set at all times because of the way the landing gear was designed.

### STEERING

The Apollo LRV features full time 4-wheel steering, which is animated in the LRV 3D model. While the actual Apollo rover was equipped with independent front and rear Ackerman steering linkage, the astronauts drove mostly with front steering only - the combined front and rear steering mode was called "crab" steering, and was not used very much as it was uncomfortable for the astronauts. The Apollo 15 crew was forced to use rear steering only on the first EVA, because the front steering was not functioning (it started working for EVA's 2 and 3).

### BATTERY ENDURANCE

NASA's Apollo LRV has been designed to operate for a minimum of 78 hours on the lunar surface on a single charge from two non-rechargeable batteries. As well as driving the motors, this power was used to operate the various communication and video equipment on board the lunar rover. The maximum cumulative distance rover was designed to cover during the entire mission was 92 km, and since no other power-consuming systems are simulated on the rover, this figure alone has been used to calibrate the endurance of the rover in simulation. Thus, the rover will be able to cover approximately 92 km on a single battery charge, and, assuming average cruising speed of 12 km/h, the battery charge should last approximately 7.6 hours.

### RECOMMENDED HARDWARE

As mentioned before, the best way to enjoy Lunar Rover simulator is to use a joystick that has a twistable handle which controls Z-axis (yaw, or rudder)). This way, you can steer the rover the way it was steered by Apollo astronauts. If you do not have Z-Axis capable joystick, you can assign the rudder to the roll axis and steer the rover that way. Also - if your joystick does not have the thrust slider, you can assign the pitch axis of your controller to control the thrust. Although this was the way the real LRV was controlled, we found it tedious having to constantly push on the joystick to keep it moving, and found the thrust slider to work much better.

Another very useful piece of hardware is the **Naturalpoint's Track-IR** device, used for tracking user's head movement and adjusting the point of view in the Virtual Cockpit. We found this device to be extremely useful, reliable and user friendly, and it gave us an amazing point of view, as close to the real astronaut view as possible. We were able to look around in any direction, and swoop down for a closer look of gauge readouts. The promotional videos on our web site were recorded using this device.

# INSTRUMENTATION

The LRV's instrumentation (control and display modules) are situated in front of the control handle and give information on the speed, heading, pitch, and power and temperature levels.

Navigation is based on continuously recording direction and distance through use of a directional gyro and odometer and inputting this data to a computer which keeps track of the overall direction and distance back to the LM. There is also a Sun-shadow device which could give a manual heading based on the direction of the Sun, using the fact that the Sun moved very slowly in the sky (This device is not implemented in the simulation). The available instruments are:



## 1 Ampere-Hours readout

This readout indicates the charge level of the batteries. It is, in effect, a fuel gauge for the electrically-powered lunar rover. The batteries on the rover were designed to last for approximately 79 hours of nominal operation and they could not be recharged. In the simulation, the only way to recharge the batteries is to add a full charge of 100% to each of the batteries through the Fuel/Payload menu of the simulation.



## 2 Voltage/Amperes readout

Indicates the Voltage and Amperes levels in each of the two batteries. This instrument has a dual scale that indicates both Volts and Amperes. A switch to the right of the instrument is used to choose between Volts and Amperes readout. Nominal Amperage is indicated by bracketed scale.



## 3 Battery Temperature readout


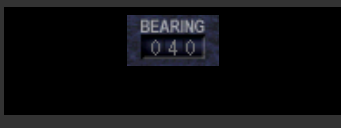
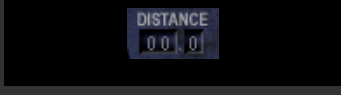

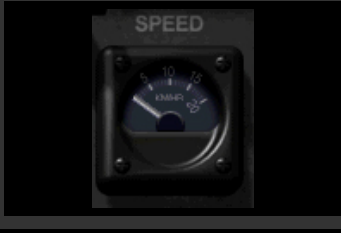

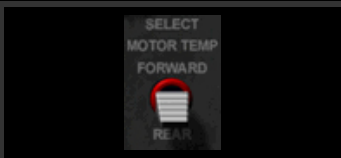
Dual readout indicates the temperature level in both batteries. Nominal level is indicated by the bracketed scale.



## 4 Motor Temperature Readout

Dual readout indicates the temperature level in drive motors. The readout indicates the Left/Right motor temperature, and the switch to the left of the readout selects between front and rear bank of motors. Nominal level is indicated by the bracketed scale.



5	<h3>Heading</h3>	
	<p>A circular moving scale, with the marker at the top indicating the heading of the lunar rover, in degrees. Essentially, a gyroscopic compass which was calibrated using the Sun Shadow Device (non-functional in the simulation).</p>	
6	<h3>Bearing</h3>	
	<p>Digital bearing indicator shows the bearing of the starting point, or from where the System Reset switch was last activated. A bearing readout of 0 indicates that the starting point is directly ahead, and a reading of 180 indicates that the starting point is directly behind. During Apollo missions this readout was used to, in a sense, "find your way home" to LM (lunar module).</p>	
7	<h3>Distance</h3>	
	<p>Total distance traveled, in km with the resolution of 100 m, from the starting point, or from where the System Reset switch was last activated. This readout in essence is an odometer with a reset switch.</p>	
8	<h3>Range</h3>	
	<p>Range readout indicates a straight-line range, in km, with the resolution of 100 m, from the starting point, or from where the System Reset switch was last activated. During Apollo missions, this readout would indicate a shortest distance to LM, which should have not exceeded 9.7 km due to the crew safety. This readout would have been re-set using the System Reset switch at the beginning of each of the LRV sorties (usually, 3 per mission)</p>	
9	<h3>Speed</h3>	
	<p>Rover speed is indicated using analogue gauge, in km/h. Cruising speed is between 10 and 15 km/h. Maximum speed attainable is approximately 22 km/h on downhill slope. Please note that downhill speed is limited due to the internal motor resistance. Gene Cernan of Apollo 17 holds the current off-world land speed record, at a breakneck speed of 17 km/h. According to his own account, he attained this while going down a lunar hill in LRV under full power.</p>	
10	<h3>Vehicle Roll/Pitch Scale</h3>	
	<p>This dual scale instrument indicates Roll and Pitch of the vehicle, in degrees. The scale can be manually flipped to display either Roll or Pitch. Click on the instrument to flip between Roll and Pitch modes.</p>	
11	<h3>Motor Temperature Selector Switch</h3>	
	<p>This switch is used in conjunction with Motor Temperature Readout gauge (4) to select between forward or rear bank of motors. The gauge then displays the motor temperatures of the left and right motors, forward or rear bank.</p>	

## 12 Battery Volts/Amperes Selector Switch

This switch is used to show either Volts or Amperes on each of the two batteries. The values are displayed on the dual scale of the Voltage/Amperes gauge (2). Note that the Voltage readout indicated is the double of the actual voltage.



## 13 System Reset Switch

This switch is used to reset the readings of Distance, Range and Bearing indicators. If this switch is used, the information on the starting point of the mission will be lost. This switch is typically used at the start of every rover excursion and is used to find the way back to the starting point. During Apollo missions, the Distance, Range and Bearing readouts were used to find the way back to the Lunar Module.



## 14 Warning Indicator Flag

This flag is actuated automatically when either of the batteries exceed thermal operating limits, or any of the motors exceed maximum thermal operating range. Flag is manually re-set by clicking on it.



## THERMAL MODEL SIMULATION

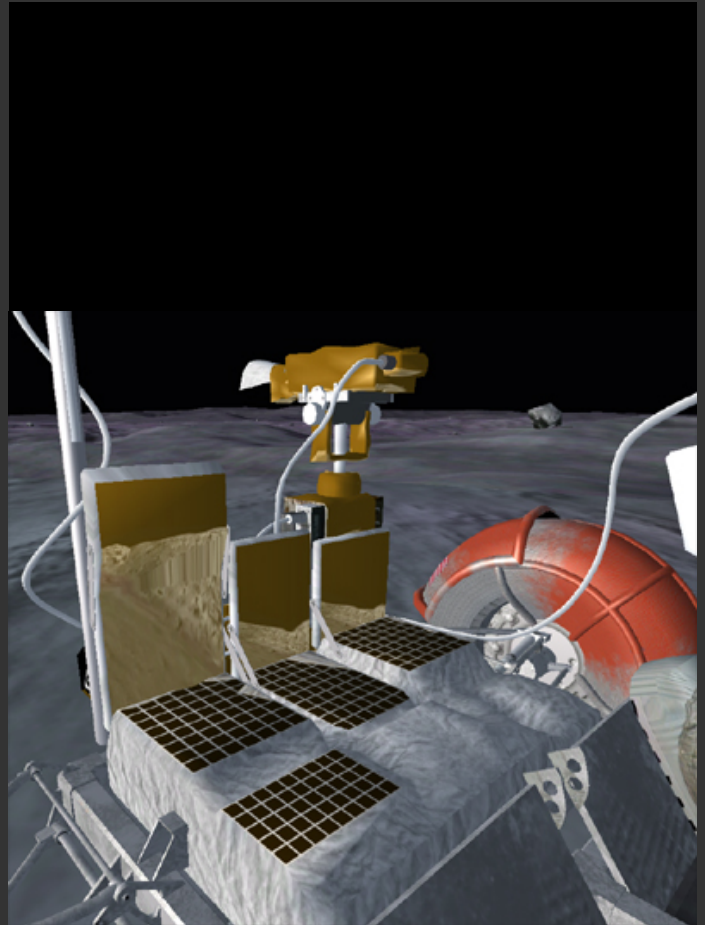
Background

### LRV Thermal Control Subsystem – Development, Deployment, and Dust!

by Ron Creel, Member of the Apollo LRV Team

The function of the Thermal Control Subsystem (TCS) was to maintain all LRV components within specified temperature ranges during transit to and operation on the Moon. The TCS had to be engineered and function concurrently with the other subsystems of the LRV and fit within an allocated budget of only 10 pounds. The LRV's electrical components could not be allowed to get too hot or too cold. This did not just apply to the LRV's operation on the Moon, but these issues also had to be considered during launch to orbit, orbit of the Earth, trans-lunar flight, lunar orbit, and the time after landing before deployment and operation on the Moon. Additionally, thermal control was required for the Space Support Equipment (SSE) which supported the LRV in the Lunar Module (LM) and allowed the LRV to be secured during transit and then deployed onto the Moon's surface.

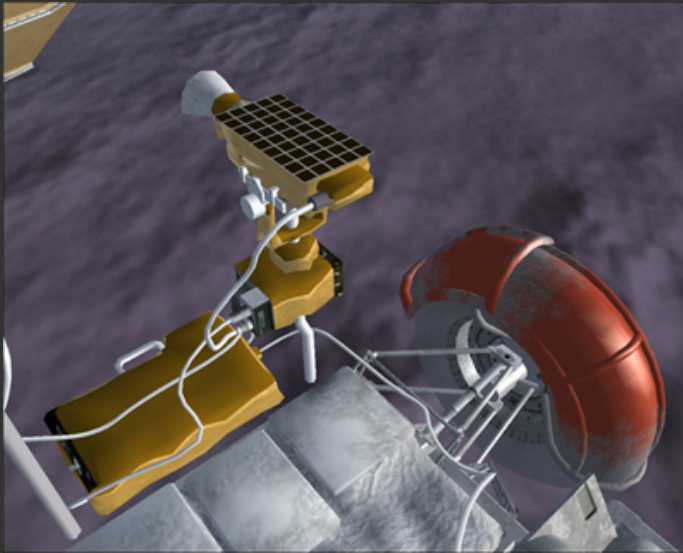
During trans-lunar flight, the combined Command and Service Module (CSM) and LM spacecraft was put into a slow rotation of about 3 revolutions per hour, known as the "barbeque" mode, in order to uniformly balance solar heating and radiation to space and thereby maintain spacecraft temperatures. Based on the survival and operational requirements for the LM, the astronauts, and their life support systems, the mission profile that the LRV would be exposed to on the Moon would be during a 78 hour sunlit period of the lunar surface temperature cycle which constituted the "lunar morning." This included solar elevation angles from 7 to 50 degrees, and lunar surface temperatures ranging from about 50 deg. F to 200 deg. F.



In addition to operation on the Moon in 1/6 gravity in a hard vacuum environment, the potential problem of adverse lunar dust effects on vehicle surfaces and components was an important factor that had to be characterized for this vital subsystem. For this reason, Earth based tests had been conducted in 1967 regarding this potential problem and how to minimize its effects. From these test results, it was known that the presence of lunar dust on surfaces would significantly increase absorbed solar heat. Testing of a variety of dust removal methods resulted in the selection of dust removal using a brush, which appeared to work well in these Earth based tests. Additional tests of the LRV wheel and fender assembly with a lunar soil simulant were conducted in a reduced pressure chamber in the NASA C-135 airplane (Vomit Comet) flying special loops to simulate the expected 1/6 gravity. It was verified in these tests that the fenders were a vital element to direct the trajectory of lunar dust stirred up by the wheels, and protect LRV components from exposure to the dust.

Based on all of these requirements, a semi-passive TCS for the LRV was implemented. This included the use of passive thermal control techniques consisting of selected radiation surface finishes, heat sinks, flexible thermal straps, multi-layer insulation, and low thermal conductance component mounts. The electronic components with the tightest temperature limits were grouped together in an insulated compartment with dust covers over space radiators in the forward chassis area. The insulation was composed of 15 layers of thin sheets of perforated aluminized mylar with interstitial layers of Dacron net in between, and Beta cloth for protection on the outside. It was assumed that all exposed LRV crew station and mobility subsystem components would be covered with dust on the Moon.

The TCS approached complete autonomy within the specified mission parameters, imposing only one constraint with regard to parking between traverses and requiring only one astronaut interface at the end of each driving traverse to initiate the automatically terminated cooldown of the electronics by opening the dust covers over second surface space radiators. It was originally desired to have the TCS be totally autonomous and not require any interaction with the astronauts. For the electronics grouped in the forward chassis area, a closed up ammonia boiler, like those ultimately used on the Space Shuttle Orbiter, was considered, but was just too heavy.



During operation, the 60 pound batteries were a great heat sink for their own internally generated heat, and an additional heat sink for some of the other electronic components. Flexible thermal straps were designed and tested to enable heat conduction from the Signal Processing Unit (SPU) to Battery 1 and from the Directional Gyro Unit (DGU) to Battery 2. The Drive Controller Electronics (DCE) had to be positioned too far from the batteries for effective thermal strapping. Passive thermal “heatpipes”, which are used extensively on present day spacecraft, were not mature enough designs at the time of LRV development, so another heat storage and transfer method was needed. Therefore, fusible mass “wax tanks” were used to store excess heat generated in the DCE (3.5 lbs. of Octadecane wax) and also for the SPU (2.25 lbs. of Eicosane wax) during operation.

The added advantage of these wax tanks was that they acted as “thermal dampers”, that maintained the DCE and SPU at constant temperatures while the wax was being melted. Then, the wax would be solidified for re-use when the dust covers were opened at the end of driving on each EVA and thermal radiators on top of the batteries and wax tanks were exposed. It was planned to have the dust covers automatically close using bi-metallic spring actuators when battery temperatures reached a safe lower temperature.

Ensuring that the TCS was up to the task fell to the engineers in the Propulsion Division of the Astronautics Laboratory at the Marshall Space Flight Center (MSFC) in Huntsville, Alabama. There were hundreds of engineers working on the LRV at NASA and its subcontractors, scattered across the United States. A fortunate few were recent college graduates who had the opportunity to work on one of the most challenging and exciting programs they would encounter in their careers. One of those young engineers was Ronald A. Creel. Ron had served as a cooperative education student in college and came to work full-time at MSFC shortly after the LRV program was launched in 1969 and was immediately assigned to engineering pursuit of the design and testing for thermal control of the LRV Mobility Subsystem. This involved working with the AC Delco Electronics Division of GM in Santa Barbara, which was in charge of development of the Mobility Subsystem. Creel was involved with the thermal vacuum testing of the LRV brakes, fluid damper, and steering system in the fall of 1970.

This was followed by computer simulation modeling and thermal vacuum testing of a 1/4 mobility subsystem at the LRV prime contractor Boeing facility in Kent, Washington. Creel also worked on additional modeling and thermal vacuum testing of the LRV forward chassis that would include the batteries, Signal Processing Unit (SPU), Drive Control Electronics (DCE), Directional Gyro Unit (DGU) - indeed, anything electrical having to do with the LRV. In addition, human factors involving the surface temperatures that the astronauts would come into contact with were also a critical issue. This was the “time-temperature” constraint for all surfaces which might come into contact with astronauts or their extra-vehicular mobility units (suits and backpacks).



These and other factors went into the preparation of the software thermal models used to both help in the thermal design of LRV electrical and other subsystems and also in verifying thermal performance for all expected storage and operating environments. Correlating of these thermal models with test data was very important. This allowed these “clean” test models to then be altered to match expected operation on the Moon and generate realistic temperature predictions. LRV surface optical properties (solar absorptance and infrared emittance) were regularly measured in order to adjust the computer thermal models that took into account these factors, as well as internally generated and externally applied heat loads to verify expected performance.

“A primary concern,” Creel said, “was being able to have the LRV thermal control system be responsive to the variations of driving and operating of the LRV’s on the Moon and the need to fully support the astronauts during all nominal and contingency operations. Thermal computer models were refined for thermal control system verification and mission planning based on correlation with thermal vacuum test results, which included the full-up Qualification Test Unit, which was really put through its paces in the large vacuum chamber in Kent, Washington with dynamometers on each wheel and solar simulation at a sun angle of 60 degrees, which exceeded the expected level for planned Moon missions. Creel was very proud of the ultimate successful performance of the LRV thermal control system and that thermal modeling for mission support was ultimately rewarded with receipt of the astronaut’s “Silver Snoopy” award. This was for simplifying a complex and cumbersome LRV thermal model into a much more responsive and useful thermal model for mission support.”

The only real problem encountered with operation of the LRV thermal control subsystems was the inability to remove lunar dust from radiators. This caused batteries and other electronics to run “hot” and even had to be turned off at times – it was good that there was a redundant battery to compensate. Accidental loss of fender extensions resulted in additional lunar dust being deposited on the LRV’s and thermal radiators. And when the astronauts tried to brush off the dust, it could not be adequately removed. The thermal engineers found that the Moon is, indeed, another and very different world than the Earth. Simulation of these “dust” effects on Earth will continue to be a challenge for designers of future Moon and Mars transportation vehicles. Therefore, a “dust challenge” was added to the course for the NASA Moonbuggy Race for High School and College teams. The students had to adapt their vehicles to traverse a simulated lunar dust environment. The teams which were best able to negotiate this simulated “obstacle” were rewarded with Apollo Lunar Rover posters.

## IN-SIM THERMAL SIMULATION FEATURES

TerraBuilder's Apollo LRV simulation features a simple thermal model simulation. In reality, rover's surfaces were exposed to constant unrelenting solar radiation. This was especially affecting rover's batteries, which were sensitive to heating. To alleviate the possibility of overheating, the batteries were equipped with top-mounted "second surface" mirror radiators which would help dissipate the excess heat buildup. These, however, would get ineffective as the dust builds up on top of the radiators and greatly decreases their ability to dissipate the excess heat. In order to cut down on the dust buildup, the battery radiators were protected by the covers that could be opened when needed. The battery temperature is monitored on the main console readout, and if it exceeds the upper tolerance level in any of the two batteries, a warning flag will be automatically actuated indicating the overheat condition on any one of the monitored components. In such a case, the battery covers can be lifted by clicking on them, so that the excess heat can be dissipated through the battery radiators. The covers can be closed by clicking on them. Note: In the simulation, there is no effect or the damage to the batteries if they overheat. It is up to the user to take action to cool down the batteries and simulate the procedures, or, ignore them and just enjoy the ride.

In-simulator battery cool down procedure:

Condition	Readout	Procedure
Warning Flag activated	One or both of the batteries temperatures are outside the operating limits.	Re-set the Warning Flag
		Raise the battery radiator covers
		Wait until the battery temperature is back inside the nominal operating limits (this can be expedited by speeding up the simulation rate)

Another area of heat buildup are the four direct-drive electric motors connected to the wheel axles. As with any electric device, they would heat up during the normal modes of operation. The higher the RPM, the higher the rate of heat buildup. Their temperature is monitored on the main console readout, and, as with the batteries, if it exceeds the upper tolerance level in any of the four motors, a warning flag is automatically actuated. The rover should then be parked for a while in order to cool down the electric motors, allowing their temperature to fall back down to the nominal operating levels. Note: In the simulation, there is no effect or the damage to the motors if they overheat. It is up to the user to take action to cool down the motors and simulate the procedures, or, ignore them and just enjoy the ride.

Motor cool down procedure:

Condition	Readout	Procedure
Warning Flag activated	Any or all of the motor temperatures are outside the operating limits.	Park the rover
		Turn off the motor power
		Re-set the Warning Flag
		Wait until the motor temperature is back inside the nominal operating limits (this can be expedited by speeding up the simulation rate)

## SIMULATION EFFECTS AND FEATURES

### INTERACTIVE ROVER FEATURES

The following is a list of interactive rover features. They illustrate the functional elements of the rover. These elements can be activated **ONLY** in the Virtual Cockpit view, however, they are visible in all views.

User-actuated animated fender extensions: you can lower and raise fender extensions by clicking on them (this was done only once, after the LRV deployment). Activated in 3D (Virtual) cockpit only but visible throughout the sim.

User-configurable astronauts' helmet shades: you can lower/raise gold visor, side shades and the center shade with a flip-up window. Activated in 3D (Virtual) cockpit only but visible throughout the sim.

User-adjustable High gain antenna in azimuth and elevation axis. The Antenna sways slightly when rover is in motion, suggesting a loose fit and adding a bit to realism. Activated in 3D (Virtual) cockpit only but visible throughout the sim.

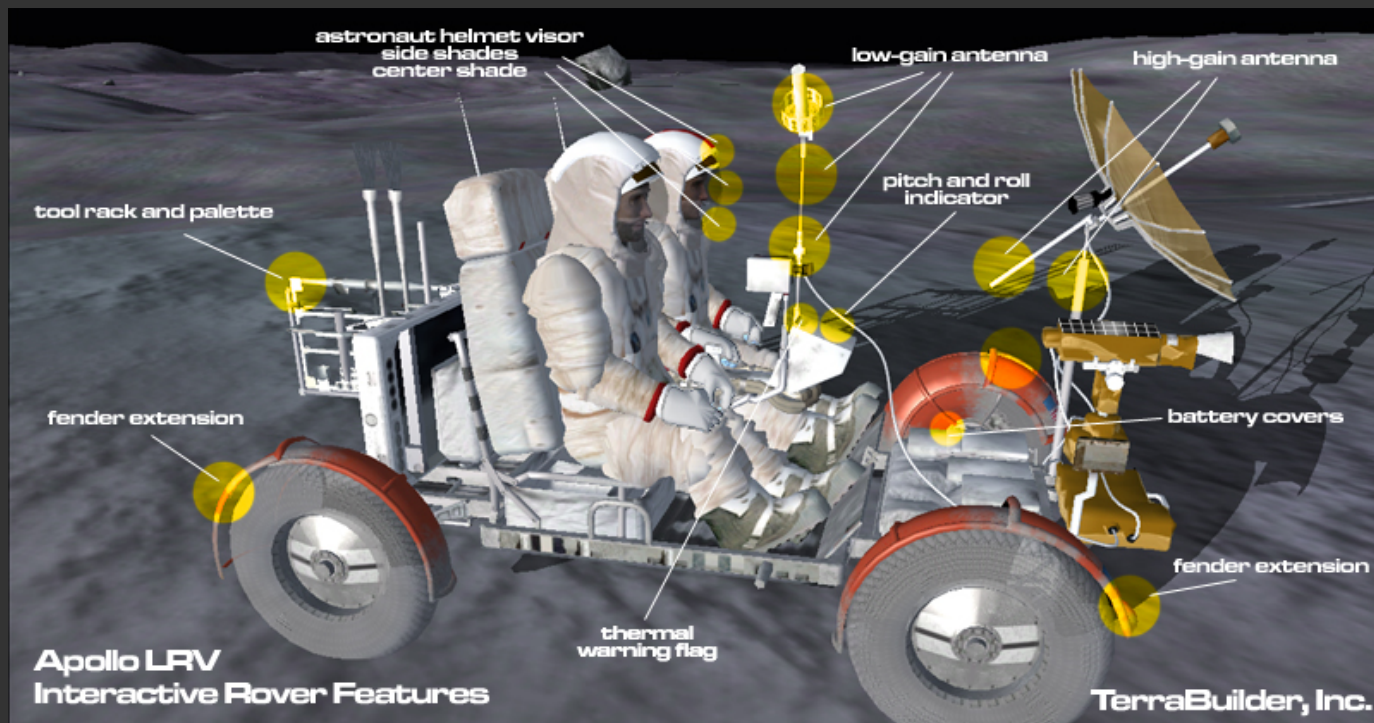
User-adjustable low gain antenna in azimuth, elevation and height axis. As with HG antenna, it sways slightly when in motion. Activated in 3D (Virtual) cockpit only but visible throughout the sim.

User-actuated rear tool rack - opens and closes, revealing the tool rack detail. Activated by selecting "Door Open" FS command and visible throughout the sim.

User-actuated battery covers with a real-time reflective mylar material. User can click on the covers to reveal battery radiators and cool the batteries off. Activated in 3D (Virtual) cockpit only but visible throughout the sim.

User-Flippable, fully functional pitch and roll indicator, just like the real thing! Activated in both 2D and 3D (Virtual) cockpit only and visible throughout the sim.

User re-setable fully functional Temperature Warning Flag. Activated in both 2D and 3D (Virtual) cockpit only and visible throughout the sim.



### DETAILED ANIMATION OF THE ROVER COMPONENTS

The following is a list of non-interactive rover animations:

Accurate suspension linkage animated to react to surface bumps. Wheels independently bounce and dip, with moving dampers and suspension arms.

Mast-mounted High Gain and Low Gain antennae, and a film camera have a bit of a "sway and rattle" during the LRV motion, suggesting a loose fit.

Animated 4-wheel steering, with the accurate animated steering linkage, pivot members and pushrods.

Two astronauts, seated and animated when in turn: they lean into turn and their heads turn in the direction of motion.

## SPECIAL EFFECTS

TerraBuilder's Apollo LRV features several special effects that enhance the feel of the simulation. They include:

**Wheel tracks** - When in motion, LRV wheels leave the wheel tracks in the lunar regolith as it traverses over the surface. Each wheel leaves its own track in the soil, so if the rover is going straight, the rear wheel tracks will be laid on top of the front wheel tracks. If the rover is turning, 4 tracks will be visible, depending on the geometry of the steering. Please note that the FS's effect engine is not perfect. It was designed to leave aircraft tire marks on a perfectly flat airport taxi surfaces - it was never designed to display wheel tracks over an uneven terrain. As a result, the display of the wheel tracks in the simulation may suffer from display glitches, namely, the complete disappearance of the tracks, and tracks (and pebble and dust effects) being displayed above the surface level (this happens usually when traversing downhill). A simple fix to either display glitch is to switch mode to "Tower" (this resets the elevation readings) or to stop the rover and get it going again. The tracks fade away and disappear after 30 seconds - this is necessary because if they were persistent, there would be a lot of extra polygons to draw the scene and the display performance would quickly degrade

**Dust clouds** - Four wheel surface contact points emit clouds of lunar dust while LRV is in motion, creating a dusty trail effect. This effect is also susceptible to intermittent display problems due to the known FS glitch.

**Loose pebbles** - Along with the dust clouds, contact points spew loose pebbles behind the wheels. Both dust and pebbles, along with the wheel tracks, may start to display incorrectly, progressively deviating upwards from the lunar surface level. This is a known Flight Simulator glitch.



There are 4 levels of special effects available. The choice of the amount of special effects depends on how capable your graphics hardware is. The levels are:

- No Effects
- Dust Effects
- Dust and Pebbles Effects
- Dust, Pebbles and Tracks Effects

Tracks effects are very demanding on graphics hardware (particularly on the hilly, uneven terrain), and will cut down on the display performance, which will manifest in a less fluid driving experience. In order to activate the effects levels, you will have to open the "aircraft.cfg" folder (located in the rover's root directory), look for the "[EFFECTS]" section and follow the instructions enclosed.

## SOUNDS

Since the real lunar rover was obviously operating in the vacuum of space, most of the audible sounds produced by it were completely muted, due to the lack of sound propagation media. Indeed, this was verified by Eric Jones of Apollo Lunar Surface Journal. The only sounds heard while driving in LRV were the sounds astronaut's Portable Life Support Systems (PLSS) made, and obviously, the comm chatter. While we strived for the complete authenticity, we gave ourselves a bit of artistic licence and introduced several sounds to the LRV simulation experience. While driving in the 2D or Virtual Cockpit, the electric motors produce a low-level whine, with the pitch increasing with RPM. The rover also has a slight rumble, and there are bumps and thumps audible as it hits uneven surface features. In the outside view, only the bumps and thumps are audible.

## NOTES ON PERFORMANCE

The rover is modeled in extreme detail, and might perform poorly on systems with lower-end graphics hardware. This is partly due to the fact that the rover is an open-cockpit vehicle, and as such, most of the vehicle geometry has to be displayed while in Virtual Cockpit mode. Ordinarily, normal closed-cockpit environments would not need to display vehicle parts which were not visible from the inside of the cockpit. In cases of severe performance degradation, you can tweak FS's display parameters to gain some of the performance back.

Performance degradation occurs when traversing hilly and uneven terrain. This problem is inherent in FS, as the airplanes were never designed to move over uneven surfaces. The performance improves greatly if the rover is driven on the flat terrain. Driving fast on the hilly terrain also increases the risk of severe damage to the mechanical gear. In particular, driving fast over the bumps will result in front or rear wheel damage which will disable the rover and require the re-loading of the vehicle. Driving downhill will speed up the rover a bit but not to the extent that it would if the wheels were completely free to rotate. The reason for this is that the motors offer resistance when not under power (akin to "engine braking", leaving the car in the 1st or 2nd gear while going downhill). This will, in effect, prevent rover to freely roll down the hill beyond safe speeds.

### Uncontrolled pitch-ups ("wheelies")

In certain situations, while driving the rover over rough terrain, you may experience a pitch up of the rover - especially if going over small hills or climbing over a crater rim. This is due to the torque of the rear motors, inertia, high center of gravity and low lunar gravity - all contributing to a potential flip-over of the rover. To remedy the situation, immediately reduce the power to minimum and apply the brakes. This will minimize the torque in the rear motors and hopefully stabilize the vehicle. If that does not work, use the Yaw key ("Y") to stabilize the rover on the surface.

### Bouncing

If you are driving the rover with the crash settings checked off (making the rover indestructible), it is possible that you will periodically encounter uncontrollable bouncing and "flying" of the rover, depending on the type and roughness of the terrain. This is a known FS problem, and it is, again, due to the fact that originally, FS was not designed to have aircraft driven over the mountains and hilly terrain. The best way to fix this situation is to put on the brakes and reduce the power to minimum. If that doesn't help, use the Yaw key ("Y") to stabilize the rover on the surface.

## Specifications

<b>Manufacturer</b>	Boeing, Delco (subcontractor)	
<b>Designation</b>	Lunar Roving Vehicle	
<b>Type</b>	Electrically-powered 2-man 4-wheeled surface excursion vehicle	
<b>Minimum Operational Endurance</b>	78 hours	
<b>Max Cumulative Distance</b>	92 km	
<b>Max. Safe Distance from LM</b>	9.7 km (due to the crew safety constraints)	
<b>Obstacle Negotiation</b>		
Vertical	1 ft	30.5 cm
Crossing	28" wide	70 cm wide
<b>Slope Negotiation</b>		
Climb	25 degrees	
Park	35 degrees	
<b>Pitch/Roll Stability</b>	+- 45 degrees	
<b>Turn Radius</b>	122 "	3.1 m
<b>Empty Weight</b>	457 lbs	208 kg
<b>Payload</b>		
Astronauts	800 lbs	353 kg
Comm equipment	100 lbs	45.4 kg
Scientific / photographic gear	120 lbs	54.5 kg
Lunar samples	60 lbs	27.2 kg
<b>Total Gross Weight</b>	1537 lbs	688.1 kg
<b>Height</b>	44.8"	1.14 m
<b>Length</b>	122"	3.1 m
<b>Width</b>	72"	1.83 m
<b>Seating</b>	2	
<b>Drive Type</b>	Direct Drive	
<b>Steering Type</b>	Independent front and rear Ackerman steering linkage	
<b>Motor Power ( X4 )</b>	0.25 HP	0.18 KW
<b>Battery Output ( X2 )</b>	36 V	
<b>Cruise Speed</b>	6 mph	10 km/h
<b>Top Speed</b>	8 mph	13 km/h