MARS ROVERS UPDATE!

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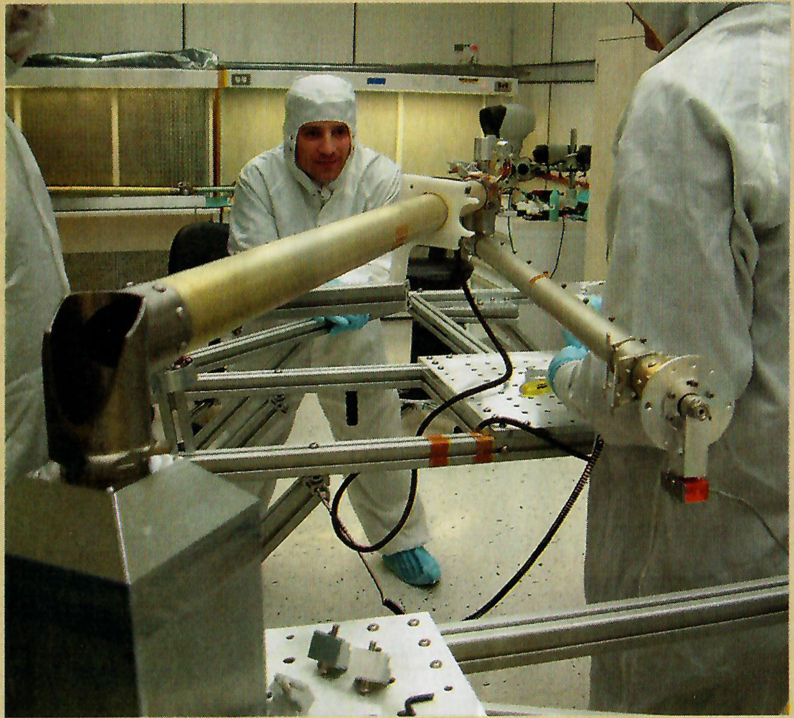
The Evolution of Mars Robotic Arm Technology



Dr. Jason Bardis has been designing space mechanisms and structures since 2005. He designed the launch locks and other major components for the Phoenix Lander Robotic Arm, as well as created and executed the arm's suite of static load tests. For the Curiosity rover, he led the mechanical design of both the Zoom and Fixed Focal Length Mastcams, and he also supported the arm development.

Robot asked Dr. Bardis to share his thoughts with our readers on the evolution of planetary exploration robotic arms.

When sending robots to space, heritage is king. Heritage trumps innovation and advances. If something worked on a previous mission, we use it again instead of experimenting with the "state of the art."

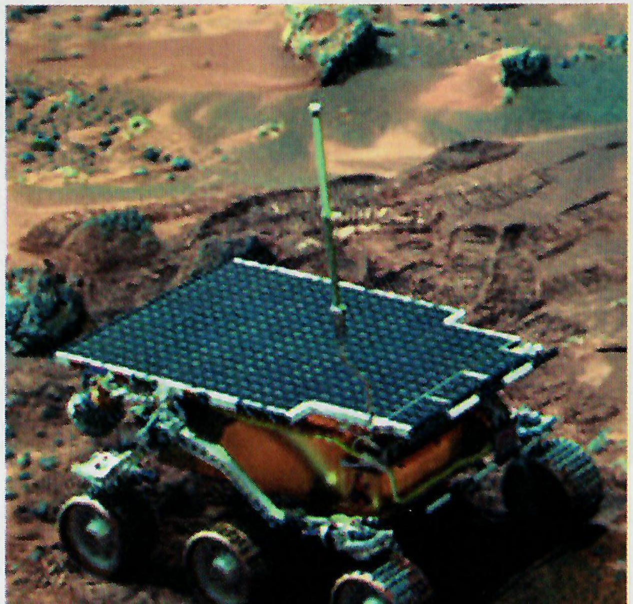
Therefore, the actuator architecture for the Phoenix Robotic Arm was very similar to that on the Instrument Deployment Device on the Mars Exploration Rovers Spirit and Opportunity. Simply put, the Phoenix arm was essentially a bigger, stronger, stiffer Spirit arm with different geometry.

Curiosity's robotic arm design was a departure from the previous two missions arm designs in that all of the

Dr. Bardis looks up the business end of Phoenix's arm during static load tests (photo courtesy of MDA US Systems, LLC).

nism. Lifted up and forward, the body would then rest on the Martian soil while the skis rotated over and down again, for another lift. A rude form of autonomous steering was used, with a simple bump switch consisting of two parallel rods signaling the rover of an obstacle impeding progress. Once triggered, the switch commanded the machine to attempt to steer around the obstruction. Some ability to discern the best direction to turn was included. Shuffling along at 1 meter (3 feet) per hour, it would stop every 1.5 meters to await commands from Earth, a trend continuing in later rovers. Prop-M consumed about 5 watts of power.

The website cyberneticzoo.com has interesting information, and a



attention. In a radical technological departure from the historical standard of using a rocket based deceleration system, the Jet Propulsion Lab made an impressive decision to use airbags to cushion the landing. These were not the movie-stunt style, which deflate upon impact. Instead, they chose fully inflated bags that caused the Pathfinder to bounce wildly across the Martian surface. After separating from the parachute system a short distance above the surface, the lander impacted at 14 m/s and limited the impact to only 18 G of deceleration. The first bounce was 15.7 meters (52 feet!) high and continued bouncing for at least 15 additional bounces.

The rover carried both 0.22 square meters (2 square feet) of solar cells

Thoughts From Dr. Bardis

actuators were provided by a different vendor. However, the remainder of the arm design had much in common with those of the previous arms, except again being bigger, stronger, and stiffer than the Phoenix arm. Another difference is that the Spirit and Opportunity arms applied very little force on Mars when operating the instruments, whereas the scoop and rasp on Phoenix and the hammer drill on Curiosity applied significant forces.

One common design feature on all of these arms is the use of multiple layers of flex cables for all power and data transmission. The flex cables are flat copper traces embedded within polyimide, and they run along the arm tubes and wind around many times over at each rotary actuator joint, much like a clock spring. This allows each actuator to have a wide range of angular motion between its hardstops without ever pulling the wiring taut.

Possibly a more interesting apples-to-apples comparison is the arm for the Mars Surveyor 2001 Lander, which was built and delivered before the mission was cancelled, and the arm for Phoenix. The Phoenix design was based heavily on the 2001 arm, but many components were analyzed more thoroughly and updated: aluminum for the arm tubes instead of carbon fiber composite, larger elbow and wrist launch locks with stronger springs, a flex cable with right angles inherent in its fabrication vs. a straight flex cable with folds introduced at the assembly level, etc. Interestingly, the old 2001 arm has been removed from storage and will be refurbished, tested, and sent to Mars on JPL's InSight geological mission, 15 years after this arm was intended to go to Mars and 9 years after its more sophisticated successor launched on Phoenix.

(made by Micron). Sojourner operations were supported by Rover Control Software, which ran on an Earth based Silicon Graphics Onyx2 supercomputer.

Communication with the lander was via 9600 baud radio modems (but limited under "real world" conditions to around 2600 baud) with a theoretical range of about half a kilometer. The Silicon Graphics machine in mission control allowed command sequences to be generated using a graphical interface, using 3D goggles supplied with imagery from the lander, viewing a vehicle model and driving with a spaceball controller.

BEAGLE/MOLE

The United Kingdom attempted to join the Mars Rover club in 2003 with the Beagle 2 lander, which carried the Planetary Undersurface Tool, or "Mole." This diminutive crawler used a compressed spring mechanism was designed to allow movement across the surface at a rate of 1 centimeter every 5 seconds and to burrow into the ground and collect a subsurface sample in a cavity in its tip. Unfortunately, the Mole joined its Soviet predecessors in a deployment failure from the Mars Express spacecraft.