By Pedro Vaz Teixeira

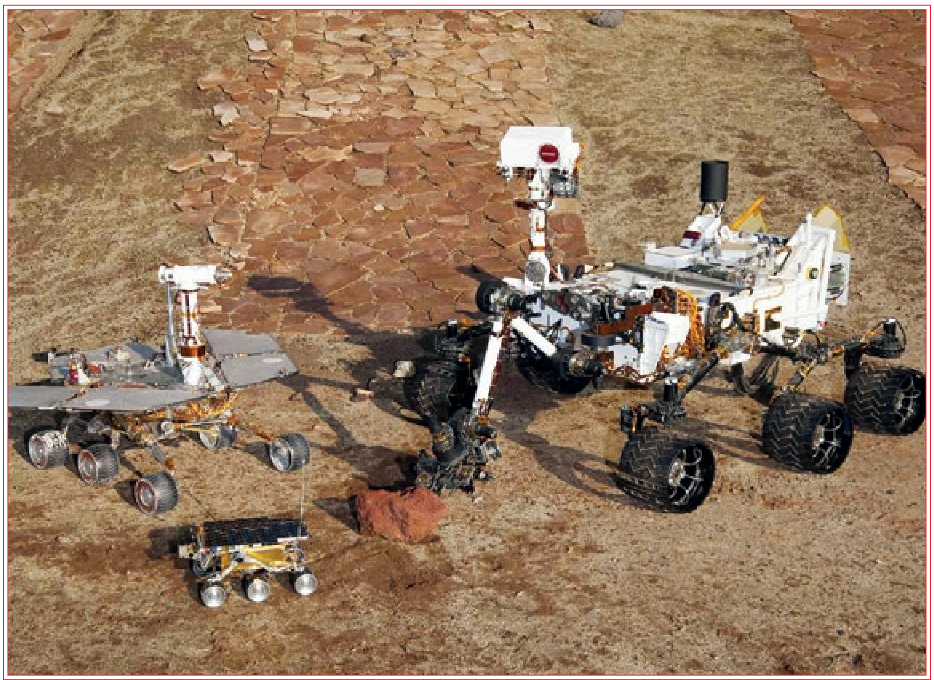
# Curiosity: The Path to Success

On the 6th of August, the Mars Science Laboratory (MSL) Rover Curiosity performed a textbook landing on the surface of Mars - an amazing feat of engineering that made the news all around the world. We contacted Rob Manning, Chief Engineer for MSL, at the Jet Propulsion Laboratory (JPL) to find out more about the history behind the mission.

Long before working on MSL, Manning was Chief Engineer for Mars Pathfinder - NASA's first mission to Mars since the twin Viking missions of the 1970s. Whereas the Viking landers resorted to a powered descent to the surface, Pathfinder's lander pioneered the use of a new entry, descent, and landing (EDL) technique wherein a descent stage decelerated an airbag-covered lander to hover a few tens of meters above the surface before dropping it. After bouncing to a halt, the lander deflated the airbags and opened its 'petals', setting free Sojourner, NASA's first rover to the red planet. Sojourner was a pioneer in its own right, testing critical systems such as the rocker-bogie suspension and navigation algorithms, modified versions of which would later be used by Mars Exploration Rovers (MER) Spirit and Opportunity and MSL Curiosity.

> "Imagine a lander with a rover and a rocket lying on top"

After Pathfinder, Manning continued working on a Mars Sample Return (MSR) mission. "We were working on the Mars Sample Return project and I was in charge of a huge lander," Manning recalls. While Pathfinder had validated JPL's new approach to EDL, a sample return mission posed new and significant challenges. "At the time we were having all sorts of difficulties building a lander that can accommodate the very large masses of both the Mars ascent vehicle and a sample rover on the 'roof' of the lander," Manning explains. "Imagine a Viking- or Apollo-like lander with a rover and a rocket lying outside, on top. That was the architecture, and we were struggling on how to make that work."

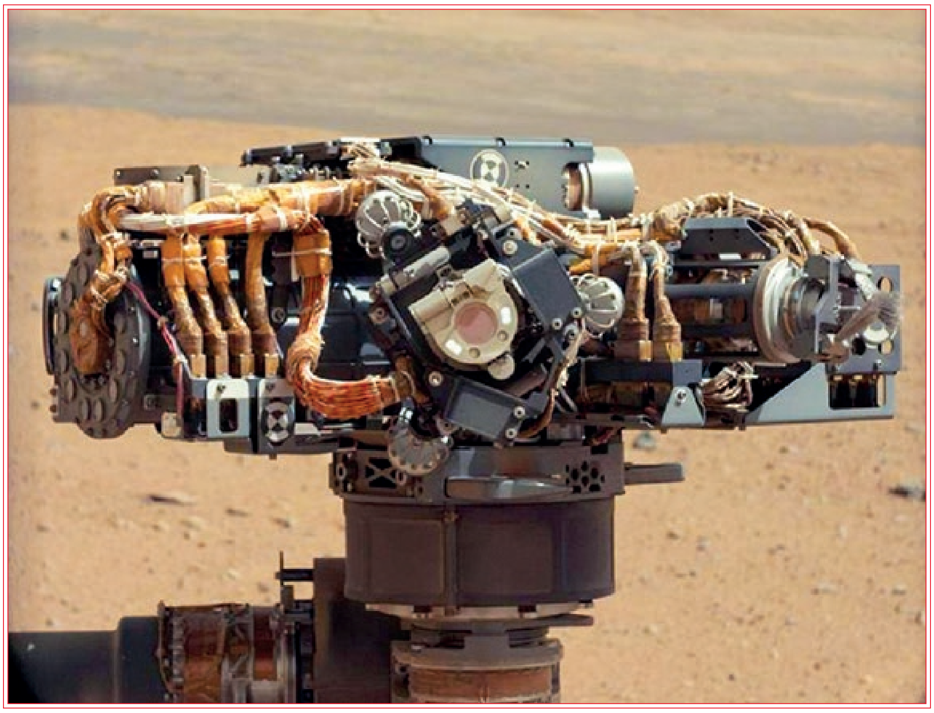


**Three generations of Mars rovers: Sojourner (front), MER (left) and Curiosity. The vehicles shown are flight spares and test models for the actual Martian units, photographed in JPL's Mars Yard.** - Credits: NASA/JPL-Caltech

## A Helicopter Named Sky Crane

The MSR lander project was cancelled following the failure of both the Mars Climate Orbiter and the Mars Polar Lander in 1999. With the funding left from the failed projects, Manning gathered a team of experts to work on new EDL concepts: "Over the course of about two months we came up with a whole family of possible landing architectures for delivering a large rover to the surface of Mars." Among these concepts was the idea of moving from a solid to a more controllable (throttleable) liquid rocket system for the descent stage, allowing a rover to land directly on its wheels thereby making all-around airbags - and the lander itself - unnecessary. Still, this concept was considered to be too difficult with respect to some of the alternatives, and was not pursued further at that time.

After the twin MER probes were launched, Manning decided to resume the liquid rocket based descent stage concept they had come up with three years earlier. MER, like Pathfinder before it, relied on a descent stage that would slow the lander to approximately 0m/s of vertical speed before dropping the airbag-covered lander from a height of around 15 meters. The idea was now to lower a rover directly from the descent stage using a set of bridles. "The technique for lowering it down on the cable just a few meters above the ground [is] called the Sky Crane mode," Manning explains. "Originally it was called the helicopter mode and we changed it to Sky Crane after



**The MAHLI imager, just one of the many tools on the Swiss Army knife known as Curiosity.** Credits: NASA/JPL-Caltech/MSSS

we studied the Sky Crane helicopters." The helicopter in question - the Sikorsky S-64 "Sky Crane" heavy lift helicopter – has been used successfully since the 1960s for payload transportation and firefighting. The team decided to develop the concept, performing analysis and learning about multi-body dynamics. Soon they were able to use the rockets aboard the descent stage to control the velocities of the payload hanging below. "Everyone agreed at the time that it would be a great way to land if only you could control it safely, if only you can get the velocities under control," Manning recalls. "Well, we did: we landed at 0.75m/s vertically and 4cm/s horizontally...that's the slowest landing ever!"

> "MSL is the engineering equivalent of a Swiss army knife"

## The Complexity of Success

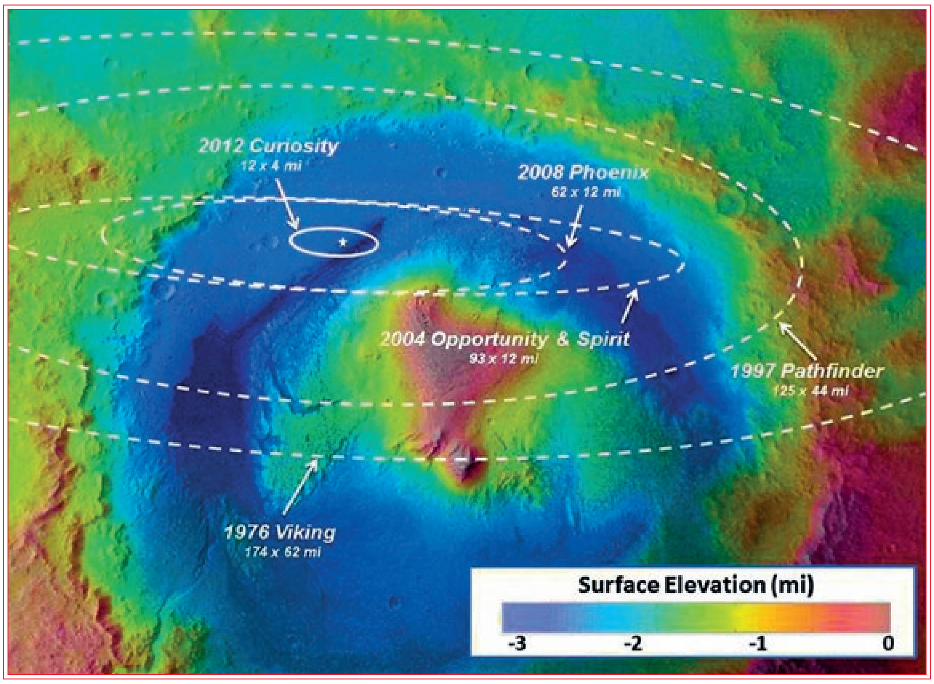
Despite having a solution to one of the most important technical challenges, success was still not guaranteed. From a management perspective, MSL represented a significant break with the past. While both Pathfinder and MER were developed by a relatively small and tightly integrated team, MSL required a different approach.

"Mars Pathfinder was a very tiny project by comparison. It was about one tenth the cost - including launch vehicle and operations - and it was done with a co-located team of people," Manning explains. "The paperwork was very light because the communication pathways between individuals were so tight; nearly everyone worked in one giant room."

With MER, the team once again took a co-located approach, this time having everyone working around the newly built testbed facility at JPL - the Mars Yard. "Our team revolved around our primary test venue, so we built a trailer park around it out of modular mobile offices," Manning recalls, "We all worked just next door to the testbed. I think that really enabled the project to be successful."

When work on MSL began around 2005, planned for a 2009 launch, it was considered one of NASA's 'big projects.' NASA, however, was unable to commit the appropriate level of resources early on due to the parallel efforts of the Phoenix lander and Mars Reconnaissance Orbiter, so the team tried to follow their previously successful approach of a small, co-located team. "The trouble was [the project] was just too big and [we] suffered the consequences by not being able to manage this complexity as well as the cost," recalls Manning.

The 2009 launch window slipped away, leading JPL to attempt a new approach. "What we failed to do with MSL in time was to organize ourselves in a big project manner," he says. "It is just like large corporations. A company is small and can be very efficient,




**Since the first Mars rover in 1976, landing accuracy of these vehicles has steadily improved.** - Credits: NASA/JPL-Caltech/ESA

> “Every mission we built has informed the others”

highly effective, very fast on its feet, and that’s what everybody wanted this project to be. The trouble is, when projects or companies get very large, in order to manage the complexity you have to compartmentalize your organization into specialities, into discipline areas.”

In the end, and as was elegantly shown on August 6th, the team adapted to the needs of a project of this scale, while taking it as an opportunity for organizational learning. “We learned what so many other people do - the challenges of going from a small company to a big company. Had we started off in the big company model, this project might have been easier. I don’t think it’d be any less expensive, but it would have been a bit easier to build. But it was a fascinating experience and I think the most amazing thing of all was that the management - and certainly the team members - adapted.”

**MSL Flight Systems Chief Engineer Rob Manning at a NASA social in August.**
Credits: NASA/Bill Ingalls

## The Evolution of Planetary Exploration

The challenges of MSL were not limited to the EDL or management: in fact, the rover represents a completely new architecture when compared with previous missions. Unlike Pathfinder, most of the functionality required throughout the entire mission is now controlled by the rover itself. Unlike MER, MSL’s ground capabilities are enormously complex. This means that in addition to being “good at launch, cruise, entry descent and landing, which includes being a pilot, a parachutist, and a precision helicopter pilot,” the rover also must be “a rolling geo-chemist and an all-terrain vehicle with many, many different skills.” Manning draws a comparison between the challenge posed by the new architecture and designing an elegant multi-purpose tool. “It is sort of the engineering equivalent of a Swiss Army knife,” he explains. “Swiss Army knives have tools for particular functions. If you add more functionality and all sorts of strange things to it, what it does is it becomes heavy, cumbersome to use, it is not good at any of the things it was good at. Basically, you’re overloading functions - you’re putting too many functions in one place as opposed to diversifying and specializing.” Finding the right balance required considerable effort from the engineers, who eventually managed to come out with a working system. According to Manning, “integration of that many functions into a single hub has turned out to be among one of the most complicated and difficult to manage attributes of this system.”

Looking at the evolution of NASA’s Mars program, Manning notes: “Pathfinder was a pathfinder for everybody, and we learned from the Viking folks, as well as Apollo. Then Spirit and Opportunity were pathfinders - huge pathfinders - for MSL.” Even beyond Mars exploration, JPL’s design solutions live on in later missions. “Every mission we have built has informed the others,” Manning explains. “There’s no doubt that our experiences on Viking and Pathfinder informed Stardust and Genesis. The experience in developing Mars Polar Lander - despite the fact we lost it - also helped inform MER. Even outside of Mars exploration, the Cassini spacecraft was absolutely essential for making Pathfinder a success, and Cassini was architecturally strongly motivated by our lessons from Voyager and then later on Galileo. They’re all so highly coupled it is really stunning.”

The successful landing of MSL is, of course, only the beginning. The roving laboratory, intended to operate for at least two years, aims to determine whether Mars is - or ever was - capable of harboring life. While doing so, it will also provide valuable information for a future human endeavour to the red planet. “MSL can offer a lot of information, particularly how we learn from the environment from the many instruments on board,” Manning concludes. “I believe over time this could revolutionize our understanding of Mars and would really make a big difference in understanding what risks are posed to human beings when they eventually get to the surface of Mars.”