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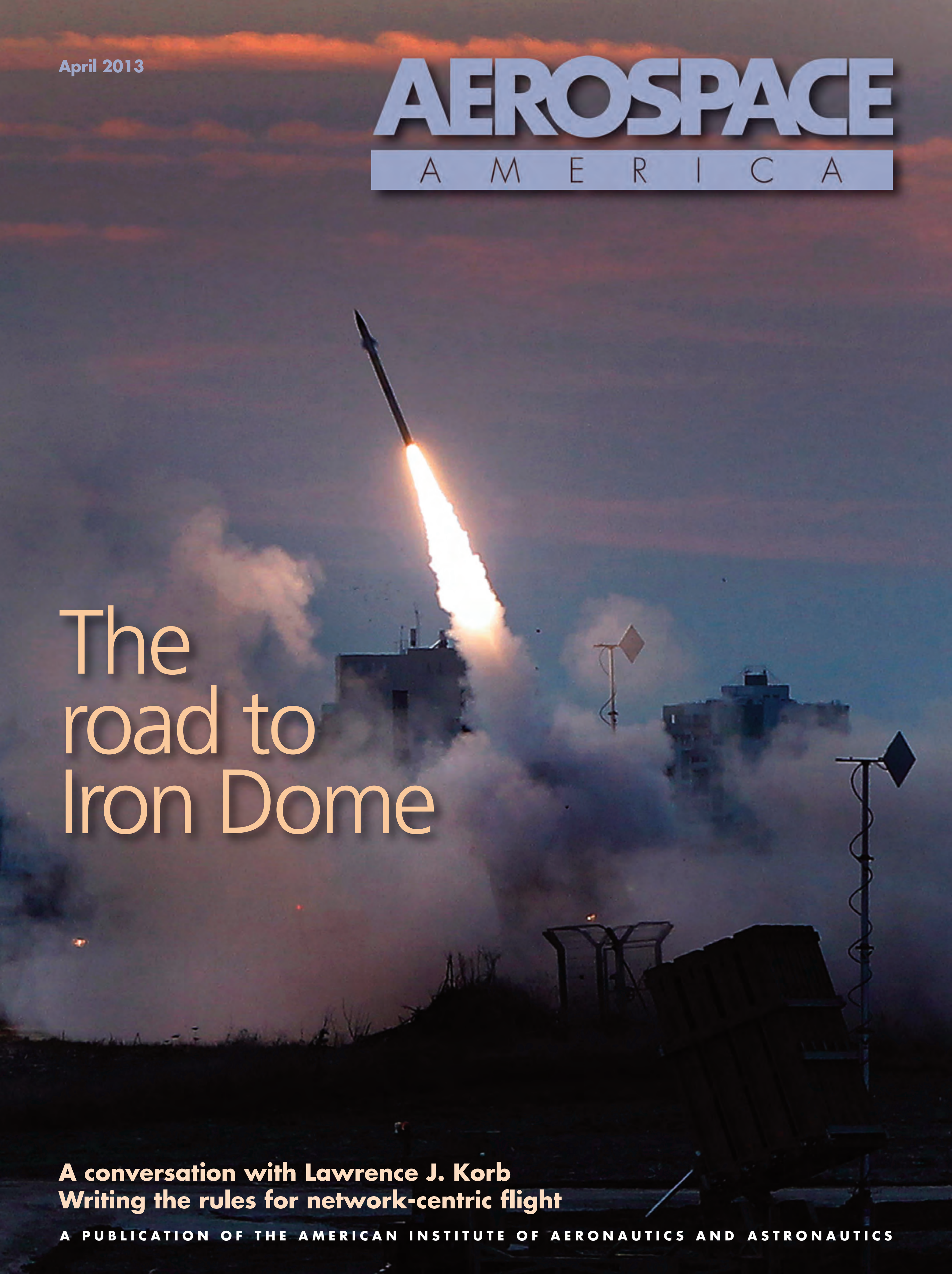

The road to Iron Dome

A conversation with Lawrence J. Korb

Writing the rules for network-centric flight

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Plan B for ExoMars

ExoMars is ESA's program to send a rover of its own to the Martian surface to search for signs of life, past or present. Mounting fiscal pressures, however, have caused the U.S. to pull out of the international program. Yet despite budgetary constraints, ESA intends to press ahead with its plans, and has turned to Russia as its new partner in the project.

The early 21st century will go down in space history as a time of sustained and successful activity on and around the red planet. With good reason, much of the limelight has been stolen by NASA, but this does not mean it will have Mars's rust-red surface to itself in the coming decade—not if ESA has its way.

Keen to follow in the tracks of Sojourner, Spirit, Opportunity, and now Curiosity, Europe's space community has been preparing a Mars rover mission for many years. ESA's Science Program Committee formalized plans in 2005 when it approved ExoMars as the agency's second Mars mission (its first was the Mars Express orbiter, launched in June 2003).

This challenging, arguably audacious mission was dedicated not simply to 'following the water' (the tag line to NASA's Mars program) but also to the search for life (ExoMars is a contraction of Exobiology Mars). As this was the first time since the Viking missions of the mid-1970s that a spacecraft had been designed specifically for this purpose, it attracted the interest of NASA scientists and eventually the promise of a contribution by way of a 'free launch.'

But when NASA pulled out of the program last year—apparently for budgetary

by Mark Williamson
Contributing writer

reasons—ESA was faced with a not uncommon predicament: how to afford to send a spacecraft to Mars.

Ticket to ride

Anyone who has followed humankind's love affair with Mars exploration knows that mission failure is almost as common as success. And the budgetary challenge of these big-ticket programs is almost as complex as the technical aspects…as the short history of ExoMars shows only too well.

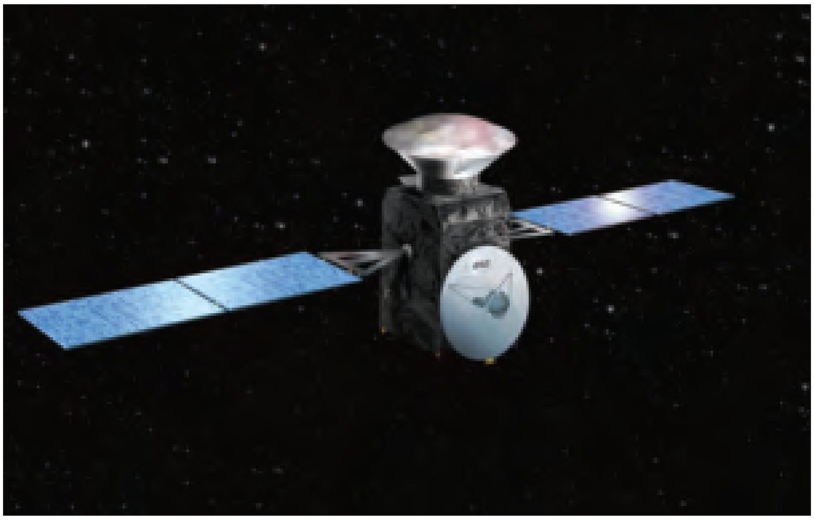
Three years after the formal approval of the mission, in the run-up to the November 2008 ESA Ministerial Conference—one of the periodic meetings where the funding fates of Europe's space dreams are decided—the future of ExoMars hung in the balance. Coming straight from the conference, ESA Director General Jean-Jacques Dordain presented a positive picture of commitment within Europe, but had to admit that member states had signed up to only €1 billion of the €1.2 billion required. As this included about €150 million for an Ariane 5 launch, his plan was to negotiate a launch contribution from either the U.S. or Russia to help balance the budget.

In 2009, at the time of *Aerospace America*'s last review of the mission (see "ExoMars: Europe rises to the challenge," May 2009, page 38), Roscosmos (Russia's space agency) was expected to launch ExoMars on a Proton as part of a 'no-exchange-of-funds agreement.' By June, however, the tide had turned toward a NASA agreement to use an Atlas V, although this would involve a mass-trimming exercise by spacecraft contractors.

The arrangement featured a dual-launch mission: A Mars orbiter and lander would be launched on an Atlas V in January 2016, followed by a rover in May 2018 (viable launch windows for Mars open roughly every two years). The rub was that ESA still needed to solicit a missing €150 million from its member states, but was obliged to wait until a ministerial meeting planned for 2012. However, even before ministers could confirm the dates in their diaries, President Barack Obama's plan to cut NASA's FY13 budget removed NASA from the equation.

It was not the first time ESA was let down by NASA (and it will not be the last, as long as NASA's strings are pulled by politicians in Washington). But it did not make it any easier to plan the timescales required for a complex planetary mission.

As ever, interactions between the heads



Instruments for the trace gas orbiter that were to be provided by NASA will now come from Russia.

of the respective agencies remained professional, even cordial, as evidenced at the regular plenary at the 63rd International Astronautical Congress, held in Naples in October 2012. Understandably, apart from a reference to the "fiscal crisis," NASA Administrator Charles Bolden avoided mention of ExoMars, preferring instead to celebrate the successful landing of Curiosity in August. Dordain was clearly disappointed that "Charlie could not come with us as planned," but was "confident in finding a solution with Russia" by the end of the year. Dordain's view of NASA's decision to fund its own Mars lander for 2016—a mission known as InSight—was not recorded.

The current plan

In the latest revolution of this wheel of fortune and misfortune, plans now call for collaboration with Russia. Roscosmos is expected to provide the Proton launch vehicles for the 2016 and 2018 missions as well as some of the spacecraft hardware. The new partnership with Russia was formally approved at the ESA Ministerial Council of November 2012, but the issue of funding shortfalls remained. Dordain is hoping to negotiate a transfer from other parts of the ESA science budget and hopes to close the budget sometime this year.

Astrium's Locomotion Performance Model, Bruno, sits in the Astrium Mars Yard. Credit: EADS-Astrium.

Although not funding ExoMars directly, the U.K. government's decision to increase its ESA spending by 25% over the next five years—an astonishing (albeit welcome) commitment given the general fiscal environment—should make Dordain's life a little easier. In fact, he joked during a press briefing at the Ministerial Council that he would be speaking English, rather than French, for the rest of his days.

Mission evolution

So how does the ESA/Roscosmos version of ExoMars differ from the ESA/NASA variant?

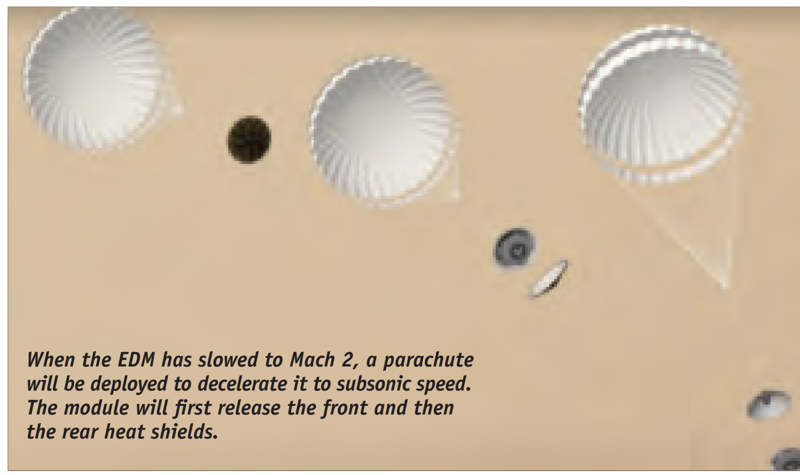
On the former 2016 mission, a trace gas orbiter and an entry and descent module provided by ESA would have been launched together on an Atlas V procured by NASA. According to Vincenzo Giorgio, ExoMars project manager at Thales Alenia Space (TAS) Italy, prime contractor for both ExoMars missions, "The [new] 2016 mission is the same as the previous one except that the instruments previously provided by NASA for the orbiter are now replaced by Russian instruments."

Likewise, says Giorgio, there is also a new plan for the 2018 mission, which would have comprised a NASA carrier module and a joint ESA/NASA rover delivered by a NASA-procured Atlas. Replacing these elements will be "a European carrier (with some Russian contribution), a fully European rover, and a Russian-led descent module (with European contributions to guidance, navigation, and control, the parachute system, and the Doppler radar)." The message to NASA should be clear: With a little help from its friends, Europe can get to Mars without you.

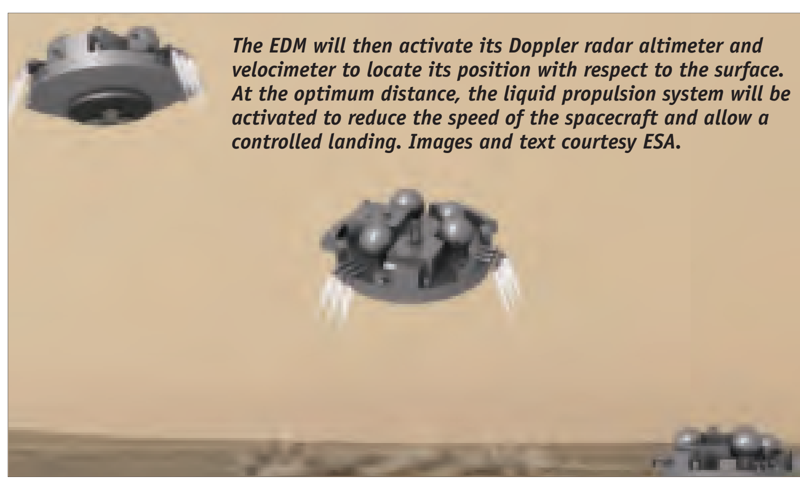
In fact, this is far from the first change to the ExoMars concept. As originally foreseen in 2005, it featured a single, all-European lander/rover mission with communications and data relay provided by NASA's Mars Reconnaissance Orbiter (MRO), which was launched that year. But delays to ExoMars, itself originally intended to launch in 2011, put MRO a bit beyond its 'use-by date' for a 2016 or 2018 mission, obliging ESA to develop a dedicated orbiter.

The 2016 mission will study the Martian atmosphere from orbit and demonstrate the feasibility of several technologies critical to atmospheric entry, descent, and landing (EDL), which, as Giorgio points out, is "the

The EDM will enter the atmosphere of Mars at an altitude of 120 km. The heat shield will protect the EDM from the severe heat flux and deceleration from Mach 35 to Mach 5.



When the EDM has slowed to Mach 2, a parachute will be deployed to decelerate it to subsonic speed. The module will first release the front and then the rear heat shields.



The EDM will then activate its Doppler radar altimeter and velocimeter to locate its position with respect to the surface. At the optimum distance, the liquid propulsion system will be activated to reduce the speed of the spacecraft and allow a controlled landing. Images and text courtesy ESA.

key to any future human exploration of Mars." The mission will also provide an orbiting telecommunications platform for relaying data between Earth and spacecraft on the surface. The 2018 mission will carry an autonomous European rover capable of extracting soil samples from as deep as 2 m below the surface, and analyzing chemical, physical, and biological properties.

Asked whether the dual mission produced additional engineering challenges, Giorgio was clear: "In general, there is no additional challenge in splitting the mission in two. In fact, including an entry, descent, and landing demonstrator on a first mission, without the rover, will provide useful GNC experience for the second mission with the rover."

Speaking at a TAS press lunch held at the Naples IAC, Luigi Pasquali, deputy CEO for TAS-Italy, admitted that ExoMars had been "a tough program," but he was upbeat about the future: "The schedule is in line, the risks are managed. We expect no surprises, even from Moscow," he said.

In addition to its prime contractor role, TAS-Italy is also responsible for design of the 2016 EDL demonstrator module EDM) and provision of its computer and radar altimeter, key components for the landing phase. TAS-France is responsible for design and integration of the orbiter module.

TAS is also developing the analytical laboratory drawer, which will carry instruments for the Pasteur scientific payload on the rover. But the design and development of the rover itself has, from the beginning of the program, been assigned to EADS Astrium, based in Stevenage, U.K.

Autonomous rover

Interestingly for Astrium, its responsibility has increased as a result of NASA's withdrawal. According to Paul Meacham, systems engineer for the ExoMars rover vehicle project, "Since the joint rover with NASA has gone, we are designing the complete rover vehicle without using NASA-supplied elements." Moreover, he adds, "The rover has returned to its original size, which is approximately a quarter of the area of Curiosity and about a third of the mass (1.6 m long, 1.3 m wide, 2.0 m high, and 300 kg)."

As per the original design, one of the key technical requirements for the rover is its autonomy, or as Meacham puts it, "the ability of the rover to drive itself and maximize the distance travelled per day without support from the control center back on Earth." This autonomy is useful, because Mars can be as much as 20 light-minutes from Earth—meaning a signal warning the rover to 'mind that boulder' could come too late—and also because it reduces the standing army required to drive and 'babysit' the rover. The plan is to communicate with the rover, via the orbiter, twice a day, transmitting commands to its onboard computer and receiving telemetry and science data collected on its travels.

Meacham views this technology as particularly critical, because ExoMars will be Europe's first rover. "It was important to raise its maturity level early in the project," he says. For this reason, quite apart from

ESA's ExoMars Rover provides key mission capabilities: surface mobility, subsurface drilling and automatic sample collection, processing, and distribution to instruments.

any side issues of partnership and funding, Astrium has continued to develop the technology and has "reached an important milestone: the demonstration of the complete autonomous system working on a prototype rover in a representative environment," according to Meacham.

Specifically, the demonstration was undertaken last September by Astrium's locomotion performance model prototype rover, Bruno, at the 'Stevenage Mars Yard facility.' The next step is to write the flight software that will control the actual ExoMars rover during its mission.

The design challenge for an autonomous rover includes enabling it to recognize terrain features, avoid hazardous areas, and plan a traverse with due regard to errors in its locomotion system, such as wheel slippage and steering errors. The ExoMars rover will navigate using a visible-wavelength stereo imaging system to build a 3D model, or 3D map, of the local environment, while onboard software plots a safe route across it.

A novel element of the rover's design is the ability to 'wheel walk.' Bruno's six wheels have lateral crampon-like features, known as grousers, to prevent slippage. They allow it to move one wheel at a time, with the others anchored, to climb particularly steep or slippery slopes.

Where planetary rovers are concerned, a combination of software simulation and physical model testing—in facilities such as the Mars Yard—is required. Based on knowledge from previous missions, a team of soil scientists at Cranfield University has even developed a replica Martian soil. The effort is part of an ESA project to improve the performance of future rovers to be used for testing the ExoMars flight model rover.

Model depicts the entry, descent, and landing demonstrator.

Of course, however clever the platform and navigation systems, it is the payload they support that will deliver the science results. Despite the change in partners, the ExoMars surface science payload remains largely unaltered. It comprises an analytical laboratory called Pasteur fed by a subsurface drill, and a robotic arm equipped with surface sampling and analysis tools. As Giorgio confirms, the main scientific goal of ExoMars also remains the same: "The search for life." Moreover, he adds, "the possibility to drill and take samples up to 2 m below the surface is the real difference between ExoMars and the Curiosity rover."

Despite the funding and organizational problems, prime contractor TAS has managed to "reuse most of the work done before, such as engineering analysis, breadboards, and technological developments," notes Giorgio. This, he says, has led to a "credible schedule" for the 2016 mission that has been scrutinized by a number of ESA independent reviews; and even some of the core elements for the 2018 mission, such as the drill and the sample preparation and distribution system, are in an advanced stage of development.

The rover's design lifetime is 218 Martian sols (about 230 Earth days), but experience with NASA rovers boosts expectations for a much longer operational lifetime. The autonomous, agile locomotion and 2-m drill make it tempting to compare the ExoMars rover with a human geologist (albeit one who never eats, sleeps, or complains). John Zarnecki, professor of space science at the U.K.'s Open University, summed up the rover's advantages when he spoke to *Aerospace America* in 2009: "ExoMars has three unique selling points: longevity, mobility, and depth. The rover will be able to cover a kilometer a day—by comparison, the U.S. rovers currently on Mars [Spirit and Opportunity] have done about seven miles over the years they have been there."

Benefits for Europe

Clearly ExoMars is important for Europe, ESA, and its industrial contractors. This is shown, not least, by Dordain's continual efforts to keep the program alive in times of financial austerity, when drilling into the surface of Mars is easily criticized as an unnecessary drain on resources. It would have been much easier to cancel the program, justify previous expenditure as 'technological R&D,' and leave Mars to the Americans.

But Europe has a long history in space

and a significant heritage in ground-breaking deep-space missions—including the first comet interceptor (Giotto) and the first entry vehicle to land on another planet's moon (Huygens). ESA's development of a fleet of small, medium, and heavy-lift launch vehicles—in the guise of Vega, Soyuz, and Ariane—proves Europe's intention to remain autonomous as a space power, while at the same time seeking cost-saving international collaboration in its programs. ExoMars is simply the latest manifestation of this long-term policy.

Indeed, representatives of the key contractors are under no misconceptions regarding the importance of the program. "ExoMars provides a unique opportunity for Europe, and Thales Alenia Space, to play a major role in the field of space exploration," says Giorgio. "I believe that any future major objectives, such as Mars sample return or human exploration, will be possible only through international cooperation, and we have to be ready by bringing heritage and real experience to the table. ExoMars will allow this."

Says Meacham, "The goal of Astrium's involvement in ExoMars is to support European exploration of the solar system and position ourselves for Mars sample return. Also, we want to promote the major role of the U.K. in robotic exploration. The technology and experiences gained through developing the ExoMars rover are applicable to future planetary rovers/landers, which puts us in a good position to design and build the missions of the future."

In fact, a U.K. contribution to NASA's InSight lander is already in development. A seismometer payload (SEIS-SP), led by Imperial College London and Oxford University, is designed to detect any 'Marsquakes,' map boundaries between rock strata, and help determine the existence of a liquid or solid core. Principal investigator Tom Pike notes, "InSight will be the first mission to look at the deep interior of another planet."

Popular destination

Historically, Mars may have proved a difficult target (since 1960, only 18 of some 43 attempts to reach the planet have succeeded), but as techniques and technology have developed, the 'hit rate' has improved and Mars remains a popular destination.

In addition to the missions already under way and in development by NASA (including the Maven orbiter and the InSight lander), the agency's Mars Program Planning Group (MPPG) has endorsed a future Mars sample return mission. Tasked with evaluating options for the 2018-2024 launch windows, the MPPG produced four possible concepts for rovers and orbiters under NASA's 'Mars Next Decade' banner, and it comes as no surprise that the innovative Skycrane system, used to lower Curiosity to the surface, is the 'hot tip' for the delivery mechanism.

Speaking in an IAC technical session, Miguel San Martin, head of GNC for the Mars Science Laboratory mission (which includes the 1-ton Curiosity rover), explained that Skycrane was the only practical way to get such a heavy rover to the surface at a survivable touchdown velocity (less than 0.75 m/sec). Moreover, it offered the additional advantage of delivery to a rough surface, because it was Curiosity's six articulated wheels themselves that performed the touchdown. As a result, according to San Martin, NASA is looking forward to using its Skycrane technology for future missions and estimates that a landed mass of up to 1.5 tons could be accommodated.

Separately, Bolden confirmed the view that Skycrane constituted a "technological breakthrough for use in future Mars missions and that NASA was continuing to "perfect the technique." However, he also characterized EDL as "a perishable skill," implying that the agency is keen to fly another Skycrane-delivered Mars probe before they forget how to do it!

As for the imperfect science of international collaboration, Bolden sought to encourage NASA's international partners with a claim that "NASA does not plan to do anything alone" in Mars exploration. Unsurprisingly, given its current budget problems and the growing national deficit, the expectation is that NASA will need help to get those Mars rocks back to Earth.

For this reason alone, NASA will be following progress on Europe's ExoMars mission with interest, possibly even a little envy. Considering the program's proven ability to rise from the ashes of budgetary firestorms, it might have been better named Phoenix…but that name had already been taken by the Mars lander of 2008.

The underlying message is that, despite the financial crises around the world, space agencies are still keen—and can find the money—to explore Mars using unmanned spacecraft. One day we might also see the love affair with Mars extended to manned missions…but that's another story.

The ExoMars drill will be able to take samples from 2 m below the surface.