Hammers Are Our Specialty

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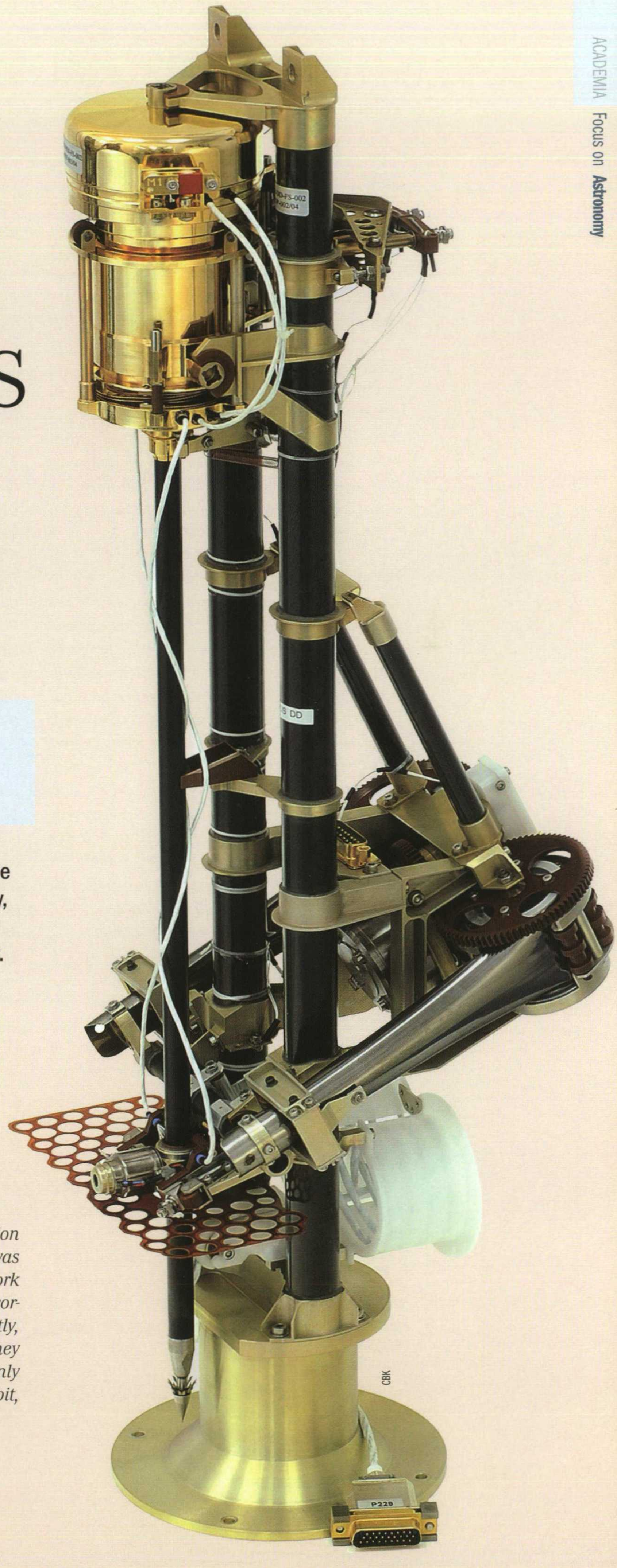
Dr. Jerzy Grygorczuk, head of the Space Mechatronics and Robotics Laboratory, led the team responsible for the construction of the MUPUS penetrator. We talk to him about the Rosetta mission, uncertainty, and patience



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Academia: During the last year, the Rosetta mission has achieved something few science projects manage by featuring on front pages of newspapers around the globe. But what exactly is Rosetta?

Jerzy Grygorczuk: *It is a research mission of the European Space Agency (ESA). It was launched in 2004, although preparation work started over a decade earlier. Rosetta is a cornerstone mission; they happen infrequently, perhaps every twenty years or so, and they set challenging exploratory tasks. It certainly isn't just a standard mission into Earth orbit, launching yet another satellite.*

So what was Rosetta's challenge?

It was to voyage hundreds of millions of kilometers away from Earth, to hone in on a tiny object out there - just a few meters across - and study it. This object is the comet 67P/Churyumov-Gerasimenko. Comets are still poorly understood and mysterious. But the Rosetta mission had an extra twist: while earlier probes had conducted observations of comets, none had included a scenario in which an object made by human hands would actually land on a comet. Additionally, until now pioneering space research had largely been conducted by Americans or Russians, yet it was we Europeans - or more precisely ESA - who accomplished a comet landing.

The probe used the Philae lander.

As well as studying the comet from a distance of several kilometers - observing its surface and analyzing the composition of the top layer - the lander was also tasked with investigating it up close. This involved making physical contact with the comet, measuring its chemical and physical properties and temperature, collecting samples from below the surface, and gathering as much information as possible about the comet's evolution. This was then to be repeated as the comet's path takes it closer to the Sun and the comet sublimates to create the visible, well-known tail. The mission has undoubtedly been a success, as most of these tasks have been accomplished.

How certain was this success prior to the mission?

When we were first preparing the mission, we asked the question, "What is the likelihood of actually hitting such a tiny target so far from Earth?" And the answer was 80%. This means that Rosetta has always been a high-risk mission. The success rate of Mars-landing missions was around 25%, with just eight probes achieving a successful landing out of the 30 or so that were launched. Rationally speaking, no one could have been 100% certain. A few days before the landing, when I was asked about the probability that everything would go according to plan, my answer was 50%. The truth is that if I'd had to make a wager on Rosetta, I wouldn't have known which way to bet (laughs).

Your team built a highly complex device for the mission.

That's right - the MUPUS penetrator, comprising over 200 parts. The story of how we got involved in the mission is actually quite interesting. The competition to construct MUPUS was launched in Germany, at the Institute for Planetology in Muenster. The project was led by Prof. Tilman Spohn, now head of the Institute of Planetary Research at the German Aerospace Centre in Berlin. I should add that our project was headed by Prof. Marek Banaszkiewicz, currently serving as president of the recently-founded Polish Space Agency. Prof. Helmut Rosenbauer, who was a member of the scientific board at the Space Research Centre, Polish Academy of Sciences, was instrumental in negotiations to involve more European teams in the mission. During the first meeting, held in Canterbury, I suggested that we design a penetrator which would be hammered in using a propulsion method which had not been used previously. This went down rather well, although the German team had already designed their own system using a miniature rocket engine. So we were told, "OK, make your device, but it will serve as a backup." We spent the first year preparing a prototype, everything was going well, but we were still on the sidelines. And then our luck came in: it turned out that systems driven by explosive materials would be excluded for safety reasons - gases escaping the rocket engine exhaust could damage other instruments, as well as contaminate the comet's environment. In the end, our solution was chosen.

What were you worried about most during the mission? What could have gone wrong?

We made several models, and conducted all the required qualification and acceptance tests, including percussive tests with overloads of up to 1000 kg. Everything was scrupulously tested according to all the procedures. But I was concerned about things we couldn't test very well on Earth. We had to be certain of the accuracy of temperature tests - we tested the MUPUS in a chamber at temperatures as low as -160°C. But no one had any idea about how hard the comet's surface would be. The figures I was given varied greatly, by three orders of magnitude. This suggested that we could be dealing with something as soft and light as fresh snow, or - at the opposite end of the spectrum - a frozen solid surface over 1000 times harder. So this was our first problem: our task was to drill

Dr. Jerzy Grygorczuk explains the mechanism by which MUPUS is extended from the Philae lander

into a surface with unknown parameters. The second concern was rooted in the fact that we couldn't test the system under microgravitation, since it is impossible to create such conditions here on Earth. We also had no idea how materials and components would behave after a decade traveling through space.

It makes space research sound like an equation with many unknowns. Time also plays an important role; Rosetta's flight took ten years, and work on the project had started another decade earlier. You couldn't draw on the technological progress that occurred during that time. How did you cope emotionally?
We worked as part of a large multinational team - with researchers from Germany, Austria, the UK, the US. We had to communicate. To start with, we exchanged information by fax, because we didn't have e-mail yet. That gives you an idea of the state of technology available 20 years ago.

As far as emotions are concerned... During the design phase, no one was focusing on what might happen in more than a decade's time. It was enough of a challenge to keep getting through various tests, which were extremely difficult, as well as designing a device which would be up to the mission's challenges. After all, for a long time it wasn't certain whether MUPUS would be carried by the probe at all. This was due to its mass - a common problem for devices used in space research. The lander was a bit too heavy, and we were trying to work out if there was anything we could remove. The probe as a whole was 2 kg over the limit, which is exactly how much MUPUS weighs - so there were attempts to eliminate it.

So what was taken out in the end?
Nothing. The weight restrictions had been set by the team of the Orbiter, the mission's main craft. And it turned out that they could easily shed 100, 200, maybe even 300 kg, so there

was no problem in the end. We discovered this a year before completing our work on the mission.

Let's get back to the comet. Why was it chosen for the honor of being visited by Rosetta? Does it have any special properties?

The original plan was to reach a different comet -46P/Wirtanen. But because Rosetta missed the original launch window, that comet could no longer be reached. The next candidate was 67P/Churyumov-Gerasimenko, a comet of similar dimensions arriving from a similar direction after spending many years beyond the Solar System. As far as its properties are concerned... well, that's precisely what we set out to find out.

The lander managed to touch down in spite of a few mishaps. What's happened to it since?

It's currently in hibernation, but it had a fairly substantial battery on board. All tasks were planned such that the battery would provide energy sufficient for a few days of study. The lander is also covered with solar panels which can recharge the battery, so the tests could be repeated. That's why the landing site was selected to have an extremely smooth surface and good exposure to sunlight. Unfortunately, after bouncing and rolling on landing, the lander ended up in rough terrain, tilted at more than 45 degrees, just 1 meter away from a cliff casting a shadow. This means that the research was conducted over just three days instead of the planned five, because there was insufficient power from the battery. The comet is now on its approach towards the Sun, so the energy reaching its surface will increase. We are hoping that in a few months - during our summertime, coincidentally - we may be able to switch on the instruments again and continue taking measurements.

So how is MUPUS now? What is it up to?

It has completed all the tasks it was given. At the start of the mission, it was secured to the lander to help it withstand vibrational overload. On our command, the release mechanism freed the penetrator. Next, the manipulator engine was unblocked, and its rotation unwound spooled tapes to extend the penetrator towards the comet's surface. Once it was in place, the hammering process was commenced. Everything was being done 'blind,' beyond the field of vision of cameras. Information transmitted by the depth sensor indicated that MUPUS penetrated just a few centimeters into the surface, rather than the projected 40 cm.

Why was that?

First of all, we didn't have as much time as we'd hoped. Secondly, the comet's surface turned out to be extremely hard. This is currently being discussed: some scientists believe that the comet's mechanical resilience is not very high, as indicated by its specific weight of approx. 0.5g/cm3, although it is also possible that the uppermost surface layer is much harder than the remainder. The two facts are not mutually exclusive, and the fact that the top layer is likely to be hard is confirmed by information from accelerometers placed at the ends of the lander's long legs. As it bounced on the surface, they registered a significant overload, which would have been impossible had the lander hit a soft surface.

So it wasn't possible to make the hammer perform its task in full - did it provide useful information anyway?

During space missions, success rates in the tens of percent are regarded as highly fortunate. I could count on the fingers of one hand the missions or instruments which have been 100% successful. Information presented during a recent meeting in Berlin indicates that broadly speaking, all systems of the MUPUS instrument, all the mechanisms and electronics, worked correctly. Measurements taken by the 16 sensors of the penetrator's drill bit were successful. The data is fascinating - it is currently being interpreted and results will be published in the coming months.

What are we likely to learn?

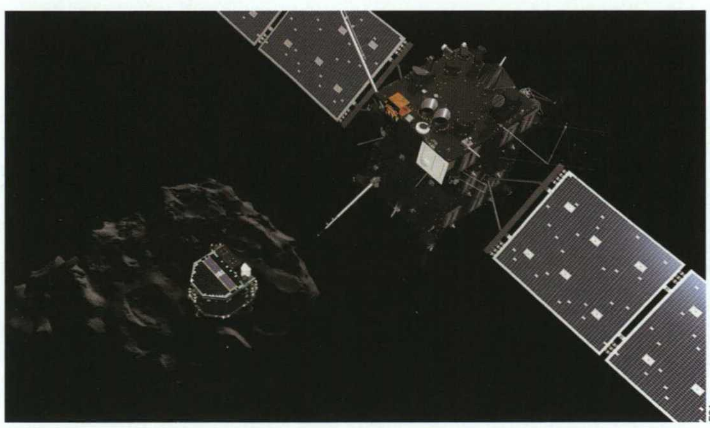
We observed a significant difference in temperature before and after the penetrator was hammered in. After it was inserted, the first two sensors located closest to the shaft recorded -170^{0}C. This suggests that the temperature of the surface and the layers immediately beneath it is lower than in the vacuum surrounding the comet. What's surprising is that we found no water ice on the surface. However, since the comet has passed close to the Sun many times over millions of years, it's no wonder that any ice once found on the surface or *beneath it would have sublimated off by now. However, it is likely to still be present at the core of the comet.*

If you were to start working on MUPUS now, would you change anything? Would new technologies have helped?
Oh, definitely. Back then, it was impossible to fit our device with a camera. But it would have been extremely useful to have been able to observe how the penetrator was released, its configuration during hammering in, the insertion process...

Space hammers are a Polish specialty. We have developed a few since MUPUS.
What I'm about to say may sound immodest, but we are currently the most advanced center in the world constructing such devices. We were the first to develop a hammering system sent on a mission to a comet. We later built "Chomik" (which means hamster in Polish) - the penetrator for the Russian Fobos-Grunt mission. Unfortunately the rocket fell into the sea. Hammer drives have proven to be extremely successful in 'mole' penetrators which are able to drill down to significant depths. Our record is five meters - the full depth of the test site. In conjunction with a private Polish company, the Space Research Centre is currently developing a drive for a German HP3 mole for the American InSight mission to Mars. Together they have secured a contract for the construction of five such devices. ■

Interviewed by **Agnieszka Pollo** and **Katarzyna Czarnecka**

What is Rosetta's quest?



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Simply put, comets are lumps of dirty ice, space snowballs formed at the far reaches of the Solar System from debris left over after its formation. They have been preserved virtually unchanged for billions of years due to the low temperatures of their environment. They are often thought of as space equivalents of archaeological digs, in that they provide an insight into our Solar System's past. They fascinate astronomers as they may reveal some of the secrets of how life first formed on Earth. In any case, by studying them we hope to discover more about the presence of water, without which life on Earth couldn't have evolved. In its early days, Earth was extremely hot, so any water present on the surface at the time would have boiled off and escaped into space as vapor. And yet, today three-quarters of the planet's surface are covered by ocean - how is this possible? One popular theory states that comets crashing into a young but cooled Earth brought water with them. More daring theories go as far as claiming that they also brought organic molecules, which became the origins of life on Earth. Space missions are conducted to try to verify such theories. Data collected by Rosetta have already revealed some surprises: the isotope composition of water on 67P/Churyumov-Gerasimenko is very different to that found on Earth. If this is also the case for other comets, we may have to search for the origins of water on our planet elsewhere. Asteroids are another potential source, albeit less efficient. Rosetta will continue accompanying its comet on its journey towards the Sun, so there should be plenty more discoveries in store.