TUMBLING STONE REVIVAL: HOW TO LAND ON AN ASTEROID

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Science fiction novels and movies did play a role in steering the public opinion in favour of space exploration. However, they also gave the misleading impression that landing on another world is easy; more so, when the target is a small body, roughly 500 times smaller than Earth. Since escape velocity is proportional to the size, the approach can take place at a speed more appropriate to a car than to a rocket. But, this neglects four serious difficulties. First, to go down to the surface of the diminutive planet you need to know which way is down. Second, you need to know where you are, and how fast you are going down. Third, you need to be able to slow down in a precise way. Fourth, you need to do have all the information at the right time.

All this becomes apparent when I am back-seat driving, right behind the shoulders of Steven Chesley and Peter Antreasian, in the computer room of the Navigation section at Jet Propulsion Laboratory, Pasadena (CA). It is 11:19 (Pacific time), they have just received confirmation that the second rocket firing has been completed, and the spacecraft is heading down, in a 5 kilometre free fall. The real time data shown on the computer screen they are watching indicates that the speed of the descent is not exactly as it should have been, according to their computations, but the difference is 800 meters (half a mile) per hour. Anyway, the last time they could do anything to correct the descent was almost one hour ago.

To understand the difficulties the two space navigators, and the entire NEAR team, are facing, you need to take into account that radio signals take 17 minutes to get from the spacecraft orbiting around Eros to the ground stations: the distance is more than double the distance of the Earth from the Sun. If the orbit of the probe is not as expected, a suitable correction needs to be computed, and then another 17 minutes for the new instructions to be received on board. Even assuming NEAR is capable of immediate reaction, and is not doing something else, like taking pictures of the asteroid, the reaction time for whatever unexpected event is about three quarters of an hour.

Even though the speed of the descent is always below 20 kilometres (12 miles) per hour, it is not at all like driving a car, unless you are driving blindfolded, being informed of where the car was at least 35 minutes ago. If the course was perfectly known, like a car on a very smooth road, this would be not too big a problem. On the Earth, with its shape very closely resembling a sphere, we know where is the direction of the centre of our planet is, because gravity is pointing to it. But the small asteroids, like Eros, have a very irregular shape; thus it is very hard to know where the arrow of gravity is pointing. The spacecraft falls down following gravity, not headed to the centre of Eros. Over 35 minutes, this could amount to a position error of hundreds of meters. Thus, it is difficult to know the position in advance, before it is too late.

After the first descent burn at 6:32, the spacecraft

turned to point the main antenna towards the Earth and sent signals allowing to pinpoint its position and rate of descent. Then it turned again, to point the camera towards Eros; after a good 20 minutes of pictures, turned back to point the antenna and send the images back. By the time the data were received at the ground station, and forwarded to JPL, it was 9:20. That was the time the race began: the two orbit computers in the JPL Navigation room had to decide the final correction to be applied to the time of the second burn, and to deliver it to the Mission Operation Center, at the Applied Physics Laboratories in Baltimore (MD) by 10:15. The spacecraft was falling down at a leisurely speed, but the rhythm of the work was breath-taking: they had to do the computation in time, no use for a late entry, no way to correct later if it was wrong. Orbit determination is a tricky business, as a matter of fact, I have much more experience than the two young men in front of me, but I have never even considered doing anything like that in less than one hour. It can be done, if the computer software has been very well written and tested, and if they do no mistake at all.

I was waiting for the last computed correction in the Navigation room, with Bobby Williams, the leader of the Navigation Team, and most of the others. Pete and Steve arrived there with only a few minutes to spare before the deadline; moreover, their two independently computed solutions were not the same! But the difference was not significant, being less than the uncertainty. Thus Bobby had signed the fax with the instructions for the last minute change: the second rocket burn has to be postponed by 17 seconds, which by the way is a very small correction. When he pushed the send button on the fax, somebody pointed out that this delivery of instructions to the Mission Operation Centre was late by 17 seconds, a nice coincidence.

Less than 10 minutes later Mission Control has sent the signal to the spacecraft. In the meantime, the spacecraft has changed again its orientation, to point the rockets in the right direction, and at 11:00 it has begun the 2 minutes 30 seconds burn. However, by the time we are informed this has indeed happened, at 11:17, it is too late to do any correction: NEAR is going to hit the surface of the asteroid in about half an hour.

Then we can just wait and watch; the data are flowing in in real time, that is, 17 minutes late. The Navigation Room is more and more crowded, at the end there are more than 20 people, many have video cameras to capture the event, including the tension appearing on the faces of the team, apart from Booby who is remarkably calm. After burn number 3, the spacecraft should be at 3 kilometres (1.8 miles) altitude, but the online data appear to indicate it is too high. This is not good: in space there are no brakes, rockets can be used to slow down the descent, but if they are used for longer than needed the spacecraft could actually start moving upwards, and after the last burn is complete it could fall from far too high, and far too fast.

The tension grows, but in a few minutes the line on one of the screen indicating the altitude appears to approach again the nominal curve. At 11:47 the signal announcing rocket burn number 4 arrives; the altitude monitor says 1.5 kilometres (0.9 miles), the spacecraft has already touched down, but we do not yet know!

At 11:59 the last burn begins; it should end at a few tens of meters above the surface. Now the spacecraft is below 500 meters (0.3 miles), and the images are incredible. More than an asteroid surface, it looks like a beach with scattered boulders. In the

Navigation room at JPL, and in the Mission Control room at APL (Baltimore), which is connected by a real time video, the feeling of triumph begins to show on the faces. But it is not over yet: how fast it is going to hit? And will the spacecraft be capable of surviving and maybe transmitting data from the surface? The

Asteroid 433 Eros was the first NEO discovered, back in 1898 and one of the largest of its kind (30 km in size). It is also the first asteroid orbited by a spacecraft in 2000, which sent spectacular close-up images of its surface.

last image is 120 meters (394 feet) from the surface, it shows details just a 2 centimetres (.8 inches) across, and it arrives interrupted by the impact: the signal indicating touchdown arrives at 11:02 (Pacific time), only two minutes before the scheduled time. According to Chesley, the impact speed is around 6 kilometres (4 miles) per hour. The rockets were firing the last part of burn number 5 when touchdown occurred, and they automatically switched off, although the control system was not designed to operate during an impact.

This result already appears to be extraordinary, actually better than expected. The descent trajectory, as seen from the tracking data, appears to be so close to the nominal solution that the difference is hard to see in the computer plots. But this is not yet all. The probe is still in touch with the ground stations! NEAR has not been designed to work while in touch with the ground, but in fact it is working, maintaining the antenna pointed towards the Earth. At first there is only a carrier, but later it will be possible to receive telemetry and to send telecommands to the probe on the surface. The landing has been so soft that nothing essential broke down.

When they were defining the goals of the NEAR mission, the mission director Bob Farquhar and the other NASA scientists and managers carefully avoided to include the landing as part of the mission definition. A spacecraft built to perform a landing, and to operate even after impact, would have by far exceeded the complexity, development phase duration and cost allocated for a Discovery mission. Landing was a deliberate risk taking, an attempt to do something by far exceeding the specifications.

This gamble has payed handsomely. This success appears to be capable to give back to NASA, to APL, JPL, and many other laboratories across the USA, the confidence they had lost in the last years as a result of a perverse combination of excessive prudence and outright failures. It is appropriate that the NEAR

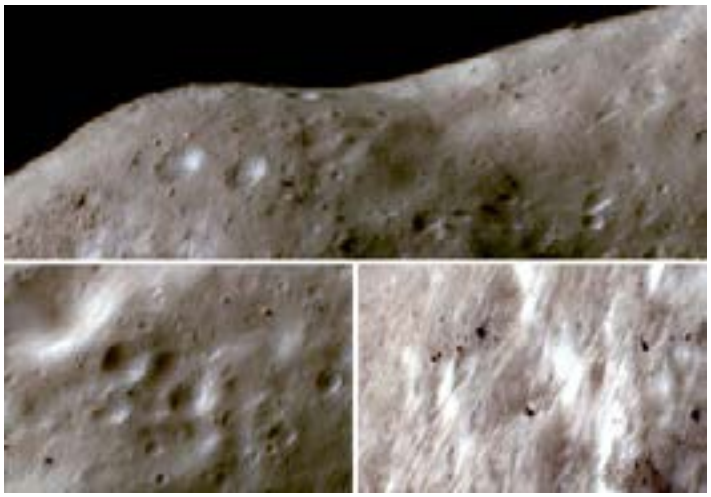
Bizarre coincidences accompanied the NEAR-Shoemaker mission: upon arriving on Valentine's day on an asteroid named after the god of love, in one of the first images sent to Earth one could see an heart-shaped feature, an illusion formed by three separate craters under peculiar lighting conditions.

Close-up view of Boulders on Eros battered surface

mission was renamed, although in a late stage (to the point that most people still use the old name), to honour Eugene Schoemaker. He was a pioneer of the understanding of the Near Earth Objects and of their relevance for our planet, he was also a man capable of taking risk; in fact while looking for impact craters in the Australian desert he died in an accident, before having had the chance to see these images of Eros.

If anything, NASA is now faced with a strange problem. Now that the spacecraft appears to be working quite well on the surface, how will NASA be able to terminate the mission before February 14? The deadline has nothing to do with Saint Valentine, or maybe it does. NEAR arrived at Eros on February 14, 2000; as gossip would have it, this was not a PR stunt but a choice made by Bob Farquhar to honour his wife, who has a small name plaque on the spacecraft, to be delivered on Saint Valentine's day 2000. Unfortunately, NASA budget for this mission includes operation support for exactly one year. Thus, will they dare to shut down a fully operational spacecraft on the surface of asteroid Eros, and this on St. Valentine's day?

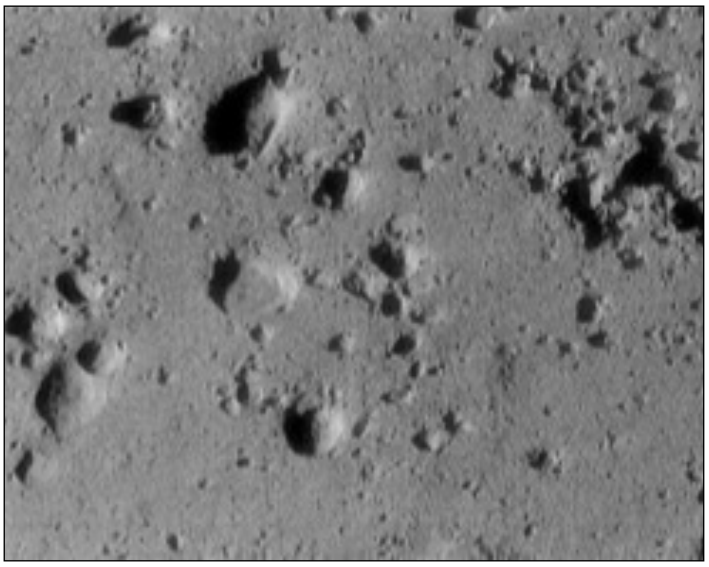
Let's wait and see.



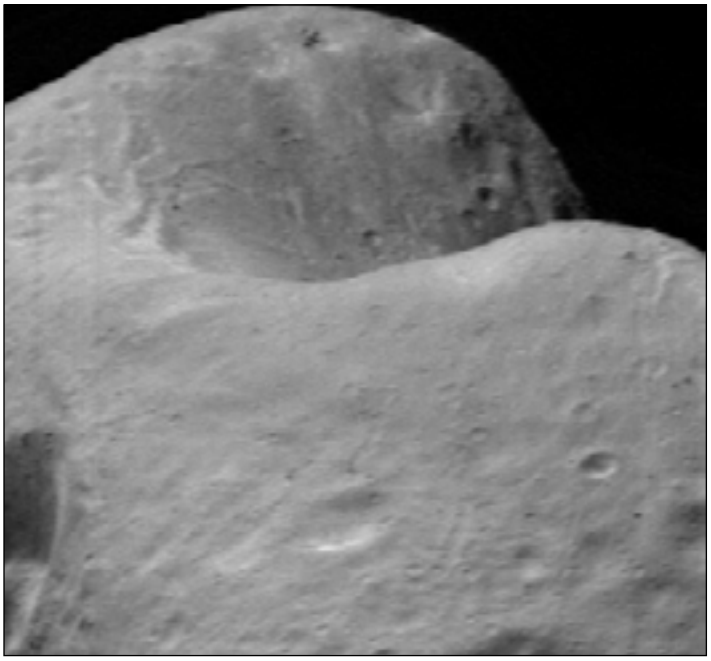
TUMBLINGSTONE REVISITED

We decided to publish the lively account of the descent of the NEAR spacecraft on Eros written by Andrea Milani as a tribute to an outstanding and passionate scientist, who passed away in November 2018. Andrea gave a seminal contribution to practically all the major fields of planetary defence, from creating the very first impact monitoring system to conceiving the asteroid deflection mission concept currently being implemented by the NASA Dart, ASI LICIAcube and ESA Hera missions. His deep knowledge of the NEO dynamics also led him to figure out how an innovative wide-field high-sensitivity telescope could bring a major contribution in timely discovering the so-called "imminent impactors". Dubbed "Flyeye" because the multi-faceted optics, the telescope is currently nearing completion by the European Space Agency. Storytelling was also one of Andrea's many interests, one he was particularly proud of, and the Neorockers are glad to have the opportunity to have him back. PS: Andrea's intriguing final question has an answer: NASA did not cut the mission on 2001 Valentine's Day, but operations continued until communications dropped on 28 February.

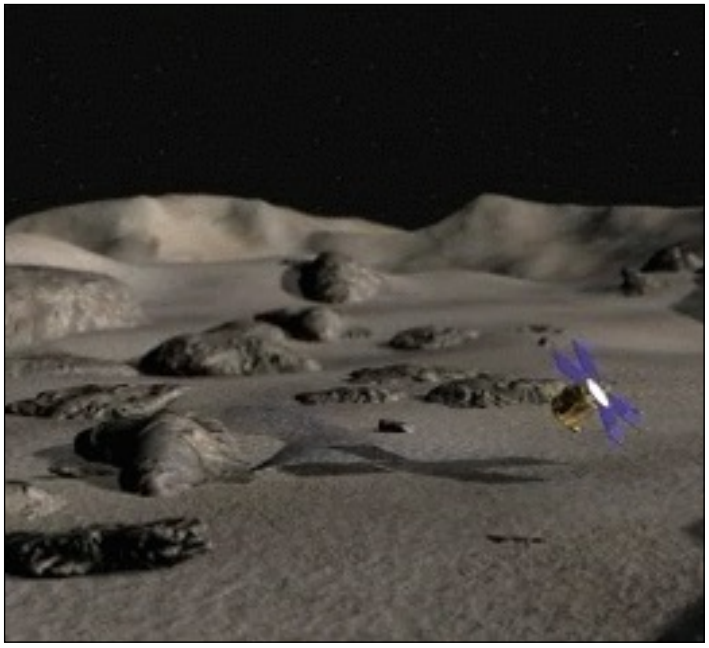
The location of the landing site



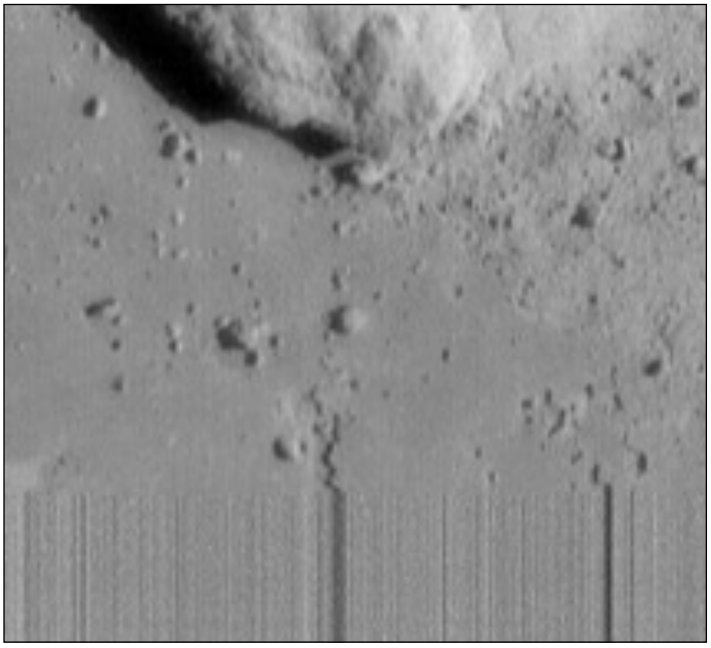
Images taken during the spacecraft descent on the surface of Eros showing the fine regloith and many sub-meter side boulders



Valleys and riffs create spectacular landscapes on Eros



EROS IMAGE ARCHIVE



The very last image received from Earth: it measures 6 meters across and the streaky lines at the bottom indicate los of signal as the spacecraft touched down the surface of the asteroid. (right)