Air and Space this Week

Item of the Week

MARS EXPRESS

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This week marks the 20th anniversary of the launch of ESA's Mars Express mission. The mission had two elements, the Mars Express *orbiter and the* Beagle II *lander. The orbiter has been a resounding success; it is still in operation meeting its science objectives and serving as a communications relay for subsequent missions to Mars. However,* Beagle II *failed completely. We've learned that* Beagle II *seems to have landed OK, but its deployment went awry. No communication from the lander has ever been received. How does one assess the success or failure of the overall Mars Express mission when half of it was a resounding success and the other half a complete failure?*

MARS IS HARD REVISITED

The Item of the Week for the August 3, 2020, Air and Space this Week was "Mars is Hard," about how difficult Space-faring nations found spacecraft exploration of Mars to be. You can revisit that item here and access the NASA-approved spreadsheet of containing information about the success/failure of spacecraft sent to Mars here.

Bottom Line Up Front: Exploring another planet remotely requires a major engineering effort. A lot of systems have to be developed, tested, integrated into a whole, and all work (almost) perfectly. In the early days, rocketry and its supporting systems were in a state of development, causing many planetary exploration spacecraft to be total failures, some even before they had a chance to operate at all. Even if the spacecraft got close enough to Mars to acquire data, sensors of that time were pretty primitive.

The demands of orbital mechanics and planetary motions strongly affect when spacecraft can be sent to Mars with maximum payload. The optimum times, "launch windows," for Mars occur roughly every 26 months, with a minimum energy transit time of about seven months. Most launch windows since the 1960s have been utilized to send a robotic explorer to Mars. You can see a two-year periodicity in the launch dates of the spacecraft in the above-mentioned spreadsheet.

[High School Teachers/Students! – JPL has put together a great educational activity built around transfer orbits and launch windows: https://www.jpl.nasa.gov/edu/teach/activity/lets-go-to-mars-calculating-launch-windows.**]**

The spreadsheet clearly shows the enormous failure rate for Mars missions in the early days, which frankly, was expected due to the complex nature of the technology required. Most early mission failures were related to the rocketry that launched them from Earth. That got better, so spacecraft lived long enough for some other new technology failure to kill them.

Everything changed, at least for NASA, with the launch of the spectacular *Mariner 9* mission of 1971. This was the fork in the road for NASA and the Soviet Space program; NASA's record in Mars exploration got better, while the USSR has had little but very bad luck there (they did much better with Venus). The *Viking* orbiter/landers of the mid-70s were very successful, as was *Mars Global Surveyor* and *Mars Pathfinder* in 1996, only partly-offset by the failures of *Mars Observer* (1992), *Mars Climate Observer* (1998) and *Mars Polar Lander* (1999).

The Turn of the Millennium completed the path of NASA Mars' exploration's improvement. Every mission sent to Mars by NASA since 2001 has been a resounding success.

MEASURING "SUCCESS"

Mars-bound spacecraft in the early days were relatively simple affairs. They either worked or they didn't. As technological sophistication increased, NASA and the USSR had missions that did produce some data from Mars, but not in the quality/quantity expected. Examples of this came during the same launch opportunity used by *Mariner 9*. The USSR launched *Mars 2* and *Mars 3* at that same time. They both sent back some data, while *Mariner 8*, launched in the same window, failed to make orbit. If the system was pass/fail, all three failed; but not all failure is equal.

The media and the various Space Agencies of the world liked a simple "batting average" pass/fail assessment, but as spacecraft became increasingly complex, and began having components that operated completely independently of each other, partial credit became an increasingly-necessary consideration.

Push-back on the notion of pass/fail became untenable with the outcome of the Mars mission that is the subject of this week's Item, Mars Express.

MARS EXPLORATION CIRCA 2001

Before 2000, Mars exploration by spacecraft was a two-nation affair, the US and the USSR. That would change with the disastrous 1998 window. Japan would send the *Nozomi* spacecraft to Mars, with the US sending *MCO* and *MPL*. All three missions failed.

NASA rallied strongly, based on the continuing success of 1996's *Mars Global Surveyor* and the 2001 launch of *Mars Odyssey* (2001, Odyssey, get it?). [BTW: *Mars Odyssey* is still in successful operation, long after its design lifetime, producing useful data and using its powerful communications system in support of subsequent missions.]

Now the Europeans wanted to join the Mars Explorers Club. The European Space Agency partnered with the Italian Space Agency to develop a major league Mars effort, called *Mars Express*. ***It was launched 20 years ago this week, on June 2, 2003***.

MARS 96

Mars Express was not ESA's first foray in Mars exploration. The Russian Space Forces (not the team that had been failing in the previous decades) had put together perhaps the most ambitious program to date. The spacecraft was a major endeavor, very large (6.7 metric tons!), and the Russians had invited other nations to contribute instruments to the science package. NASA, France, Germany, and other European countries got on board. The mission comprised a number of separate elements: an orbiter, two landers, and two penetrators (probes strong enough to withstand a landing without parachutes or retro-rockets). All elements carried a number of state-of-the-art instruments: imagers, seismometers, magnetometers, spectrometers, and more. The mission became known as *Mars 96*, for the year of its launch. Alas, it turned out that while the instrumentation of the payload was superlative, the telemetry capability of the launch vehicle was not.

Mars 96 launched from the Baikonur Cosmodrome on November 16, 1996, aboard a Russian Proton missile. The large spacecraft apparently made parking orbit OK. It would rely on a second burn of the Proton's fourth stage, followed by a boost from *Mars 96*, to send it successfully on its way to Mars. The booster burn was more of a burp, but it was enough to detach *Mars 96*, which dutifully fired its small thrusters. Without the normal thrust from the fourth stage, all that did was to put itself in a rapidly-decaying orbit. A few hours later, it reentered and crashed somewhere off the coast of South America (or perhaps on it).

NASA was spared somewhat by the success of their 1996 window's effort, *Mars Pathfinder*, the one with the air bag landing, tiny rover, cartoonish rocks, and an astonishing reach with the new-fangled Internet. But that rosy glow was lost with the ridiculous double failure in the 1998 window of both *Mars Climate Orbiter* and *Mars Polar Lander*.

The loss of *Mars 96* was a calamity, indeed, for the international planetary exploration effort.

There was a silver lining. The technological innovations and development that all of the mission partners contributed in many cases lived on in other missions to come.

Including *Mars Express*.

MARS EXPRESS MISSION

Everybody involved with Mars exploration needed a rally to get over the late 90s failures. With NASA, that would come with the 2001 Mars Odyssey mission. For ESA and others, it would come from 2003's Mars Express mission.

To help give you a sense of the timing on these missions, note that the launch of *Mars Express* came one week before the launch of NASA's first *Mars Exploration Rover* mission, *Spirit*.

ESA was the lead agency involved in planning and designing the *Mars Express* spacecraft, with significant partner, the Italian Space Agency, and other contributors, including NASA. The design and construction process were expedited, the reason for use of "Express" in the mission's name. A number of *Mars 96* instruments and other technology were utilized, along with some legacy tech from ESA's Rosetta mission, which helped the process go faster. A straightforward, but advanced, mission overview held that *Mars Express* would comprise two separate components, an orbiter and a lander. The orbiter would be called "Mars Express," and the lander was dubbed "Beagle II" after Darwin's famous research ship.

"The mission's main objective is to search for sub-surface water from orbit. Seven scientific instruments on the orbiting spacecraft have conducted rigorous investigations to help answer fundamental questions about the geology, atmosphere, surface environment, history of water, and potential for life on Mars." (reference here) Other science objectives include the characterization of the martian surface globally at 10 m resolution, with more detail in selected areas, utilizing a range of wavelengths and conducting detailed measurements of the martian atmosphere.

NASA's primary contribution to Mars Express was working with the ISA on the development of the Mars Advanced Radar for Subsurface and Ionospheric Sounding (MARSIS) instrument. Its powerful radar is capable of revealing subsurface structure and ice cap structure, as well as studying Mars' ionosphere (recall that the radio "telescope" at Arecibo was first and foremost a tool for studying Earth's ionosphere).

Mars Express is still in full operations, twenty years after launch. In addition to the data from MARSIS, *Mars Express*' instruments are making important observations of "recent" glacial activity and explosive volcanism, and its enhanced communications system still serves as a data relay for other Mars spacecraft, part of a global net now available.

BEAGLE II

The "potential for life" Mars Express mission objective was to be addressed by the *Beagle II* lander, Britian's contribution to the Mars Express effort. It carried a suite of instruments to characterize the landing site's geology and mineralogy, the physical properties of the atmosphere and surface, and search for biosignatures (evidence for past life). It would use a parachute/air bag landing system, much akin to that on *Mars Pathfinder*. *Beagle II* would, like *Pathfinder*, deflate its airbags after landing and then the petal-shaped walls of the landing would open. They were lined with solar panels to provide power.

Beagle II was released from the *Mars Express* spacecraft as it approached Mars, right on schedule and without problem. It would land on Mars on Christmas Day, 2003. Everything was looking great, but the Grinch must have intervened, for no further word was ever received from *Beagle II*, in spite of heroic efforts. The lander was declared lost on February 6, 2004.

Inquiries were held, hypotheses for failure were posed and debated, but nobody knew for sure what happened to *Beagle II*. Until January 16, 2015, when the *Beagle II* landing site was found in images acquired by the fabulous HiRise camera aboard the *Mars Reconnaissance Orbiter*. The images were subject to new Super-Resolution Restoration techniques (image stacking on steroids) to produce a rather clear view of the lander and its parachute and backshell. The lander seems to have landed successfully, but two of the lander's four petals had failed to open, and one of them was blocking the communications antenna from deploying properly. The exact reason for the failure to deploy is still unknown, but that was the cause of the failure.

MISSION SUCCESS OR FAILURE?

When I was originally tasked with coming up with a way to prepare a fair "batting average" for the roster of Mars missions, the case of *Mars Express* really bothered me. I was already struggling with the thought of partial credit for the USSR's 1971 missions, and how to the growing trend for multiple (semi) independent mission components for a single launch.

Now I was looking at a two-part mission where one part failed completely and the other was a smashing success, valuable for twenty years and counting. Nor was I oblivious to the possible political repercussions to a success-fail binary decision. This particular situation was the tool I needed to establish the absolute need for a "partial success" rating, and the need for a spreadsheet that succinctly evaluated mission elements, not missions.

The only fair assessment of the Mars Express mission is "Partially Successful." The total success of one mission half cannot totally overcome the total failure of the other half. Once the door to acknowledging an intermediate rating is open, a more-fair (IMHO) assessment of the missions and mission elements can be made and compared to success rates over time.

The resulting spreadsheet of past/present Mars missions includes six different types of missions/mission elements: Fly-by, Orbiter, Lander, Rover, Sample Return, and Mars Moons. Each element is rated Success or Failure, with a six-level code for failure types. Each launch (U.S. or "other") can be adjudged successful, partially successful, or a failure based on the performance of its various elements. The spreadsheet gives data from which "batting averages" for each type of mission elements can easily be derived.

You can access the "Mars is Hard" spreadsheet from the website's Archive: Other Stuff page or directly here. I hope you continue to find it useful!

REFERENCES

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https://mars.nasa.gov/MPF/martianchronicle/martianchron8/mars96.html

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ESA Mars Express website: https://sci.esa.int/web/mars-express

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NASA Mars Exploration page: https://mars.nasa.gov/mars-exploration/missions/express

Wikipedia: https://en.wikipedia.org/wiki/Mars_Express

Beagle II: https://en.wikipedia.org/wiki/Beagle_2; https://www.space.com/28286-europe-beagle-2-mars-lander-found.html

U.S. Participation in Mars Express: https://mars.nasa.gov/express

MARSIS: https://mars.nasa.gov/express/mission/sc_science_marsis01.html

NASM's Tom Watters is a MARSIS Participating Scientist: He was lead author on "MARSIS Radar Sounder Evidence of Buried Basins in the Northern Lowlands of Mars (*Nature*, 14 December 2006, vol. 444, pp 905-908) and other MARSIS papers.

Item of the Week Bonus!

Liquid Water Beneath Mars' Polar Cap: A Case Study in How Science Operates: The *Mars Express* spacecraft, in operation for almost two decades in orbit around Mars, carries the MARSIS instrument, a high-powered radar scanner capable of penetrating the layered terrain/polar cap at Mars' south pole. The radar signals reflected from a zone beneath the SPLD are higher than expected, much higher in some places. The best explanation hypothesis to date is that there is a layer of salty liquid water at the base of the SPLD causing the high reflection. But it isn't the only hypothesis that explains the observation! And the briny "lake" idea has some serious drawbacks. Further testing may or may not resolve the issue; perhaps additional observations are necessary. The high radar return observations are valid, and how scientists are approaching explaining those data make for a good case study in how this thing we call "Science" operates. See for yourself here.

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