Air and Space this Week

Item of the Week

MARINER 10

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*NASA's first forays into the exploration of the Inner Solar System were the ten-mission "Mariner" series. Launched over an 11+ year span (1962-1973), the Mariner missions gave planetary scientists their first up-close data from Venus, Mars, and Mercury, and established the validity of the concept of "comparative planetology." Three of the missions failed (*Mariners 1, 3, and 8*), but two of the missions were fabulous successes (*Mariners 4 and 9*). And then there was the one that capped the series,* Mariner 10*'s intrepid visits to Mercury.*

THE MARINER PROGRAM

Mariner 4 and *Mariner 9* have been the subjects of a prior Items of the Week (*Mariner 4*, *Mariner 9*). I gave an overview of the Mariner program in the *Mariner 9* Item, reproduced immediately below.

NASA expanded President Kennedy's charge to "put a man on the Moon, before the decade is out" to include robotic exploration of the Solar System. As was the case for Mars (here), Solar System exploration is very difficult. The very cutting edge of technology is required, operating under extreme conditions. And the Mariner program is an example of that dictum.

There were 10 missions in the Mariner program: Three of the ten were complete failures, which was a pretty good batting average back then!

Spacecraft	NSSDCA ID	Launch Date	Target	Outcome
Mariner 1	MARIN1*	07/22/1962	Venus	Destroyed by the RSO at Launch
Mariner 2	1962-041A	08/27/1962	Venus	Success
Mariner 3	1964-073A	11/05/1964	Mars	Launch Shroud Failed to Deploy
Mariner 4	1964-077A	11/28/1964	Mars	Success! See here also
Mariner 5	1967-060A	06/14/1967	Venus	Success
Mariner 6	1969-014A	02/24/1969	Mars	Success
Mariner 7	1969-030A	03/27/1969	Mars	Success

Mariner 8	MARINH*	05/08/1971	Mars	Failure of Second Stage
Mariner 9	1971-051A	05/30/1971	Mars	Spectacular Success!
Mariner 10	1973-085A	11/03/1973	Mercury	Success: Three Fly-bys

Mariner 1 and *Mariner 8* did not live long enough to get an official NSSDCA ID number

Note that the targets of all the *Mariners* were close enough to the Sun for the solar cells of the day to provide power for all spacecraft electrical needs. Exploration of the outer Solar System would have to wait for better technology, including a better solar cell, more capable spacecraft, and a better radioisotope thermal generator. The Pioneer class of spacecraft already in use were augmented to include *Pioneers 10* and *11*, which had a more-adequate RTG, and the *Voyagers 1* and *2* were able to go as far as Neptune (and are still operating today!) with an even-more spacecraft and powerful RTGs. But those mission lay in the future.

After the spectacular success of *Mariner 9*, only one of the inner planets had not yet been visited, Mercury, a fact well-known to Mariner mission planners. The reason that no previous Mariner mission had even tried to go there was that moving a spacecraft closer to the Sun required as much (or more) fuel than moving on away from the Sun.

WITH A LITTLE HELP FROM A FRIEND

NASA trajectory designers struggled with the limitations on then-present fuel capacities and engine power. The payload penalty with 1960s technology was too much to power a spacecraft past Mars or Venus. But those designers were ingenious sorts! If their spacecraft could not carry enough fuel (usable energy) to go as far as was desired, they would need to find a way to "steal" the energy they needed! The idea was not particularly new; it was first proposed by Giuseppe Colombo at the University of Padua and then had been kicked around for decades, but only as a theoretical exercise until actually spacecraft could be launched.

The Russians sent *Luna 3* to photograph the far side of the Moon in 1959, but knew that the Moon's position after the images were acquired would block their transmission to Earth. They aimed the fly-by to pass near enough to the Moon for the lunar gravity to deflect it enough while flying by for the spacecraft to get a line-of-sight back to the ground station that received the images.

Colombo's/NASA's ingenious solution for planetary exploration became known as a "Gravity Assist," [which is also the name then NASA Chief Scientist Jim Green chose it for his podcast that features ingenious NASA personnel (see the News: Solar System section)]. A planet orbiting the Sun has a LOT of kinetic energy and a LOT of gravitational attraction. Why not use the latter to steal a minute bit of the former?

When a spacecraft approaches a planet, they mutually attract each other graviationally. The spacecraft is much more affected, of course, since it is so much less massive. The spacecraft's speed, and more importantly, its velocity vector, is changed by the gravitational attraction of the planet. Energy is conserved in the interaction; the total kinetic energy is the same as it was before the encounter. But if the right trajectory is chosen for the encounter, the spacecraft could gain [or lose] a considerable amount of speed.

NASA has prepared *A Gravity Assist Primer* webpage that explains the physics of a gravity assist in more detail. In it, the use the following analogy. Imagine a train barreling through a station at 50 MPH. A vandal-hearted kid throws a tennis ball at the front of the engine as the train approaches. His arm is pretty weak, and he only managed to throw the ball at 30 MPH (relative to the platform). What is seen next is a matter of perspective. The engineer sees the ball coming at him at 80 MPH, the sum of the train's speed and the ball's speed. The ball rebounds from the engine at the same 80 MPH. From the conductor's perspective, the ball is rebounding at 80 MPH from him. The kid sees the ball coming back at him at 130 MPH, 80 from the rebound and an additional 50 from the movement of the spot the rebound occurred. This example is for a spacecraft gaining kinetic energy, where the train represents, say, Jupiter, the ball represents our spacecraft, and the rebound represents the gravitational interaction between Jupiter and spacecraft.

FIRST USES OF GRAVITATIONAL ASSISTS

After the Apollo program was near its end, NASA had funding to begin to explore the Solar System in earnest. They extended the capabilities of both the Pioneer and Mariner standard spacecraft designs, preparing *Pioneer 10*, *Pioneer 11*, and *Mariner 10* for use.

The *Pioneers* had an early RTG and would allow them to explore Jupiter and Saturn. With the RTG, Pioneer 10 could reach Jupiter directly and operate. However, Pioneer 11 would only be able to get to Saturn if its use of a gravity assist was successful at Jupiter.

Pioneer 10's mission was to fly by Jupiter, acquire and return data, and use Jupiter's gravity to gain enough speed to escape from the Solar System altogether. The planets were not aligned in a way that would allow Saturn to be reached, regardless of the fly-by trajectory chosen. It was launched on March 3, 1972, and reached its closest approach to Jupiter on December 3, 1972. It was fully successful in accomplishing mission goals, and NASA was able to remain in contact with the spacecraft until January 23, 2003, when it was 80 AU from Earth (!).

Pioneer 11 was launched on April 6, 1973. Its mission was to also fly by Jupiter, and use its gravity assist to fly on to become the first spacecraft mission to Saturn. Its closest approach to Jupiter was on December 2, 1974, and it flew by Saturn on September 1, 1979. It was fully successful in accomplishing mission goals at both planets. NASA finally lost contact with it on November 24, 1995.

The two Pioneers above proved the validity and utility of the gravitational assist concept. It is widely and routinely used today. The gravity assist tactic could also be used to subtract energy from a spacecraft, which is necessary to boost a spacecraft toward the Sun rather than away.

While the Pioneer flights were going on, NASA was also preparing the final mission in the Mariner program. A Mariner mission to Mercury would be the ideal "two-fer!" Planetologists would get their first good look and other data from a Mercury fly-by, and the trajectory designers would get to refine their gravity assist tactic to work "both ways," to boost a spacecraft to get farther from the Sun and to extract energy from a spacecraft to get it closer to the Sun.

MARINER 10

Mariner 10 was launched on November 3, 1973. It would fly by Venus on February 5, 1974, and use Venus' gravity to lose energy and be assisted to an orbit that intersected Mercury regularly. It would fly by Mercury three times over the course of the mission. Note the dates involved.

Luna 3 was the first spacecraft to use the gravity of the body it was studying to alter its own trajectory operationally. *Pioneer 10* was the first to use the gravity of the body it was passing to gain speed and change direction. But *Mariner 10* was the first spacecraft to attempt and succeed to change its speed and direction as planned when passing one planet in order to visit another planet.

Mission Objectives

The *Mariner 10* spacecraft had three areas to study during its mission: Venus, during the gravity assist there; Mercury, to determine basic surface and overall properties during its three fly-bys, and interplanetary Space, where it would determine the conditions as it passed between planets. It carried a suite of seven instrument packages that would make the measurements desired.

Instrumentation

Television Photography Experiment: Remember, this is state-of-the-art for the early 1970s. Digital imaging wasn't a "thing." But images of Venus and Mercury in visible light, and in wavelengths humans cannot see, would be very important. The twin television vidicon system aboard had several filters to help with "color" analysis. The cloudy nature of Venus' atmosphere was already well-known, but visible light could provide clues there, and would certainly be valuable in imaging Mercury's surface.

Infrared Radiometer: The IR radiometer detected heat energy. In the case of airless planetary bodies, the IR characteristics of the surface provide strong clues as to the nature and composition of the uppermost part of their surfaces.

Ultraviolet Spectrometer: Mercury was too small to have a dense atmosphere, but learning the composition of would be useful in understanding the near-Mercury environment. There were two UV spectrometers in this package; both used primarily at Mercury. The Occultation Spectrometer looked for the signature of gases at the edge of Mercury when it was silhouetting the Sun. The Airglow Spectrometer looked at Mercury's surface, looking for the emission spectra from the atoms in Mercury's "atmosphere" as they are bombarded by UV radiation from the Sun. Basically, the AS was looking for the Mercury version of an aurora.

Plasma Detector: Heliophysicists were just starting to understand the nature and characteristics of the "Solar wind" in the early 70s. They were particularly interested in finding how the Solar wind would interact with Mercury and its magnetic field, if any. That's what the **magnetometer** aboard was for.

Charged Particle Telescope: Astronomers were also interested in how the Solar wind interacted with cosmic radiation, which would augment data collection pertaining to the Mercurian magnetic field, if any

Radio Science Experiment: The idea of probing a planetary atmosphere by monitoring the attenuation of the radio signals of spacecraft passing behind the planet as seen from Earth was developed for/during the *Mariner 4* mission to Mars. The same technique would be used at Mercury, to augment the airglow detector results on the nature of the very-thin mercurian atmosphere.

MISSION PROFILE

Mariner 10 was launched on November 3, 1973, **fifty years ago** this week. The Atlas/Centaur booster worked properly, inserting the spacecraft into a parking orbit, needed to position the spacecraft for a second Centaur burn to put it on the proper trajectory toward Venus and its gravity assist. This was the first time a booster was asked to perform a second burn, but it worked.

A number of problems arose with the spacecraft, keeping the mission engineers quite busy.

Mariner 10 had a detector on board that could lock onto the bright star, Canopus, to help the spacecraft orient itself. However, the spacecraft began shedding flecks of highly-reflective paint, which spoofed the Canopus detector. The problem could be overcome, but it would recur throughout the mission. There were troubles with the on-board "computer," the high-gain antenna used to communicate with Earth, and the spacecraft's power system. Many of Mariner 10's problems were caused/exacerbated by high levels of thermal heating, but others were not. Thrusters and positioning gyros also acted up, to the point where mission controllers had to use the spacecraft's solar panels as "sails" to orient the spacecraft properly. An on-board tape recorder failed just prior to the second Mercury fly-by, resulting in a lower data return rate and a loss of data. For more on the difficulties faced by the spacecraft operators, see here. It was a *tour de force* of creative solutions for the operators, and their creative solutions were most definitely fine examples of "as only NASA can!"

The spacecraft made UV observations of Comet Kohoutek, then flew by Venus for its gravitational assist. During the encounter, *Mariner 10* acquired a lot of useful data. Some confirmed what *Mariners 2* and *5* had previously found, and the UV camera revealed a lot of structure in the venusian cloud deck, even though it appeared featureless in visible light. Those data confirmed Earth-based results that the upper venusian atmosphere rotated the planet every four days. Convection cells in the atmosphere over the subsolar point were also observed. A very weak magnetic field was discovered, unlike Earth's much stronger magnetism.

Venus was an important objective, but it was also a steppingstone to Mercury.

The spacecraft's orbit was altered as planned by the loss of energy to Venus, such that its perihelion now coincided with the orbit of Mercury, the period of the orbit (twice that of Mercury's) would allow for three fly-bys. The only disadvantage was that the spacecraft would be seeing more-or-less the same side of Mercury on each fly-by. A global view was not possible, and planetologists had learned to be leery of conclusions based on seeing only part of a planet/moon's surface (*Mariner 4*'s limited look did not show the representative terrain types on Mars as were revealed by *Mariner 9*).

The fly-bys occurred on March 29, 1974; September 21, 1974; and March 16, 1975. The first and third fly-bys were very close to Mercury; 437 and 203 miles, respectively.

Mariner 10's thrusters used nitrogen gas, which became depleted after the third fly-by. Contact was lost on March 24, 1975. The spacecraft presumably is still in solar orbit.

RESULTS

Mariner 10 made some fundamental observations at Venus, as described above. Over 4500 images were acquired in the three fly-bys, covering about 45% of the planet's surface. What was seen was very much like the surface of the Moon: terrains with different populations of craters and plains presumed to be akin to lunar maria. A very tenuous atmosphere, primarily of helium presumed to be a (temporary) capture from the Solar wind. Mercury was observed to have a magnetic field, and, based on the planet's bulk density, a large iron core is likely present. The data from *Mariner 10* played a large role in planning for the mission to follow.

MESSENGER

NASA conducted a second mission to Mercury, this time to orbit the planet for a detailed global reconnaissance. It was called *MESSENGER*, an acronym "**ME**rcury **S**urface, **S**pace **EN**vironment, **GE**ochemistry, and **R**anging." It was launched on August 2, 2004. It didn't enter into an orbit around Mercury until March 18, 2011, in large part because losing enough energy to orbit Mercury required a total of six gravity assists: one by Earth, two by Venus, and three by Mercury itself! Data collection began on April 4. Over 200,000 images (only 1,000 were expected) and a lot of other data were returned to Earth. Global photographic coverage was obtained, and discoveries included: that there was considerable volcanic activity on Mercury in the past, that the mercurian magnetic field was offset from the planet's center by a significant margin, that there is water in Mercury's tenuous atmosphere, and that there are concentrations of magnesium and calcium on Mercury's night side. Important results continued during the mission's two extensions, including the discovery of water ice in deep impact craters at Mercury's poles (places upon which the Sun never shines). *MESSENGER* ran out of maneuvering gas and impacted the surface on April 30, 2015.

MESSENGER was a highly-successful mission that exceeded expectations considerable, a worthy successor to the pioneering work of *Mariner 10*!

BepiColombo

A successor to *MESSENGER* is presently *en route* to Mercury. It's named for Guiseppe "Bepi" Colombo, the Italian scientist who first proposed the gravity assist tactic. *BepiColombo* is a joint ESA/JAXA mission, launched on October 20, 2018. To date, it has received a gravity assist from Earth, two from Venus, and three from Mercury. Three more fly-bys of Mercury will be needed before orbit insertion, which is planned for **December 5, 2025**. *BepiColombo* comprises the *Mercury Transfer Module* (used for propulsion), and two orbiters, the *Mercury Planetary Orbiter* (*MPO*) and the *Mercury Magnetospheric Orbiter* (named "Mio"), built by JAXA. The *MPO* has a suite of 11 instruments and will examine Mercury closely. *Mio* is designed to study the Solar wind and interplanetary dust. *Bepi/Colombo*'s initial plans also included a small lander, which would have used a rocket/airbag landing system, but it was cancelled due to budgetary constraints.

During its first fly-by, *BepiColombo* came very close to Mercury (125 miles) and was able to detect its magnetosphere, which was very compressed compared to Earth due to the much greater solar wind that close to the Sun.

One of the things *BepiColombo* will be looking for are auroral displays on Mercury. Mercurian aurorae are very different than those on Earth. They do not involve fluorescing atmospheric gases, but rather they are caused by solar X-rays impacting Mercury's surface materials. The X-rays spray bits of electrically-charged particles from the surface, which are then carried to the dark side of the planet releasing absorbed X-rays, causing an aurora-like glow. For a summary of the Mercury aurorae, see here.

DIDJA KNOW?

I just love the fact that the final footprint (for now) on the Moon's surface was made ten years ***to the day*** after *Mariner 2* flew by Venus, our first successful robotic mission to another world. What a decade of advancement and accomplishment that was, to go from our first halting step to explore the Solar System to walking on the Moon six times!

REFERENCES

Mariner Program and Initial Visits to Jupiter and Saturn

NASA: https://science.nasa.gov/mission/mariner-program

Pioneer 10 NSSDCA: https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=1972-012A

Pioneer 10 NASA: https://science.nasa.gov/mission/pioneer-10/?linkId=173095117

Pioneer 10 Wikipedia: https://en.wikipedia.org/wiki/Pioneer_10

Pioneer 11 NSSDCA: https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=1973-019A

Pioneer 11 NASA: https://science.nasa.gov/mission/pioneer-11/?linkId=178519970

Pioneer 11 Wikipedia: https://en.wikipedia.org/wiki/Pioneer_11

Gravity Assist

Historical Review of GA concept: http://mtc-m21c.sid.inpe.br/col/sid.inpe.br/mtc-m21c/2020/07.22.11.13/doc/Negri-Prado2020_Article_AHistoricalReviewOfTheTheoryOf.pdf

Giuseppe Colombo Wikipedia: https://en.wikipedia.org/wiki/Giuseppe_Colombo

NASA's a Gravity Assist Primer: https://science.nasa.gov/learn/basics-of-space-flight/primer

NASA Contractor Report from 1966: http://www.gravityassist.com/IAF3-2/Ref.%203-143.pdf
NOTE: The author of this CR, Gary Flandro, was the same person who envisioned the Planetary Grand Tour mission concept, which became *Voyager 2* after additional development work was done at JPL by UCLA grad student Michael Minovitch!

ESA (has animation of GA):
https://www.esa.int/Science_Exploration/Space_Science/Exploring_space/Let_gravity_assist_you

Planetary Society: https://www.planetary.org/articles/20130926-gravity-assist

Phy6: http://www.phy6.org/stargaze/Stostars.htm [Why Think Small?]

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

Mariner 10

NASA: https://science.nasa.gov/mission/mariner-10

Mariner 10: A Retrospective, in the *Mercury Messenger*, Issue 10, December, 2003:
https://www.lpi.usra.edu/publications/newsletters/mercmessenger/issue10.pdf

Danielson, G.E., et al., 1975, Acquisition and Description of *Mariner 10* Television Science Data at Mercury, *Journal of Geophysical Research*, v. 80, no. 17:
https://web.archive.org/web/20230307153350/https://core.ac.uk/download/pdf/77926702.pdf

Mariner Venus Mercury 1973, Case File Copy, October 15, 1973:
https://ntrs.nasa.gov/api/citations/19740002665/downloads/19740002665.pdf

A Study of Mariner 10 *Flight Experiences and Some Flight Piece Part Failure Rate Computations*: Tech. Memo 33-759, Paul, Floyd A., 1976:
https://ntrs.nasa.gov/api/citations/19760010079/downloads/19760010079.pdf

Wikipedia: https://en.wikipedia.org/wiki/Mariner_10

MESSENGER

APL: https://messenger.jhuapl.edu

NASA: https://science.nasa.gov/mission/messenger

Fifteen Years Ago (5-minute read): https://www.nasa.gov/history/15-years-ago-messenger-launched-to-orbit-mercury

MESSENGER Stories: https://science.nasa.gov/mission/messenger/stories

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

Bepi/Colombo

ESA: https://sci.esa.int/web/bepicolombo

ESA: https://www.esa.int/Science_Exploration/Space_Science/BepiColombo/BepiColombo_factsheet

JAXA: https://global.jaxa.jp/projects/sas/bepi

NASA: https://science.nasa.gov/mission/bepicolombo

NSSDC: https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=2018-080A

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

space.com: https://www.space.com/35671-bepicolombo-facts.html

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