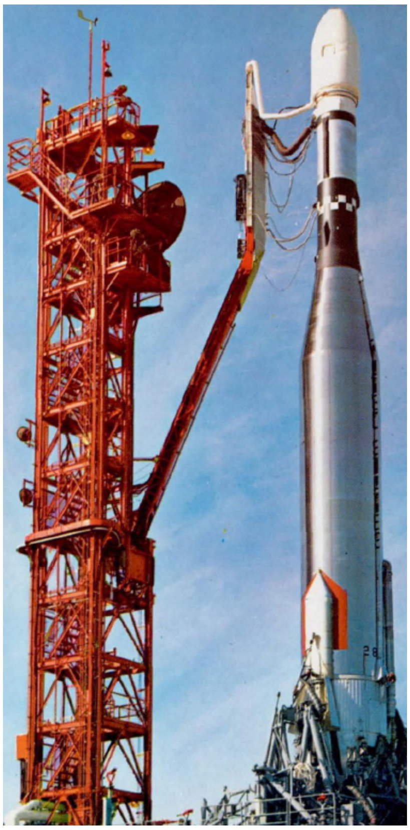
Mariner 4 :

A brief history of early space, imaging and data transmission sciences.



An Atlas, Agena, Mariner stack prior to launch at Cape Canaveral.

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Preface.

Here is some science history based on the 1964/5 Mariner 4 Mars flyby mission. Why did I do this? Well many years ago I did a university module that dealt with data transmission techniques for Mariner 4; specifically how the first television pictures got back from Mars. Sadly I have now lost that source material. However I did manage to hang onto another set from the later Marina 9 mission where the recording and transmission technology, plus post processing techniques were massively better. So this is largely a recreation of some lost memeories.

I specifically have an interest concerning Mariner 4 because for a lot of my life I earned my income from implementing data-transmission technologies beginning with a baseline data transfer rate of 300bps (bits per second) and finishing (20 years later) with 10Gbps (10 gigabits per second). The fact that the images from Mariner 4 were transmitted from Mars in 1965 at a mere 8.33 bps, yes that is not a typo, is of intense fascination to myself. Mariner 4 also has the distinction of taking and returning to Earth the first useful picture of any planet.

All photos and many diagrams used within plus most of the technical detail are from NASA and JPL archives, I also used Wikipedia as a starting point for research. Some of the following text was also extracted from variety of NASA source materials, specifically mission reports, these are mainly shown in italics. In some cases the original text has been adapted.

Some specifically useful texts were:

1. NASA Report from Mars: Mariner IV 1964-1965 NASA-EP-39

2.NASA Mariner-Mars 1964 Final Project Report SP-139

3. JPL Mariner Mission to Venus

4. NASA Technical Report 32-884 Mariner Mars 1964 Project Report: Television Experiment.

We have to thank NASA and it's associates for allowing this information and images into the public domain, at the time of the missions some of the technical information would have been very highly classified.

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This document was prepared using LaTeX.

Overview

The Mariners were a family of spacecraft designed during 1958 and 1959 for planetary investigations within the solar system. The family was effectively a common octagonal chassis structure with some propulsion and guidance to which could be attached a variety of sensors and communcations equipment. Mariners 1 and 2 were initailly launched in 1962 to explore Venus then in 1964 Mariners 3 and 4 were launched to explore Mars. Marina 3 failed because the launch shroud failed to release correctly, but Marina 4 successfully completed it's planned flypast of Mars at a closest altitude of 6,118 miles and delivered much useful scientific data throughtout and even beyond its whole mission. Many years later Marina 9 had much higher mass and was able to enter a Martian orbit and capture images probably at least a hundred times better than what 4 achieved, but that is really a separate story around an era with far higher technological ability built on earlier successes. Mariner 4 should therefore be seen in the light of being a groundbreaking mission, not just because of the distance but also because it was shown to be a technology pathway for further (and ongoing) development of robotic spacecraft.

Mariner was only possible because a new generation of Atlas boosters with Agena second stages were able to provide the acceleration to achieve interplanetary orbits for the useful mass of the spacecraft. The Atlas was also the first US booster that had the thrust to enable John Glenn to complete the first US manned orbits. The Atlas got the whole stack off the ground into a designated orbital profile, the Agena then boosted the spacecraft away from Earth into its eventual planetary trajectory required for Mars. The Agena was another key technology in orbit and beyond because it was restartable, early technology was generally ust a single burn until the fuel ran out. The Atlas was derived from an ICBM (inter-continental ballistic missile).

A major factor for the timing of the launch was that it was within a window where Mars and Earth were closest to each other in their respective orbits, this meant that flight duration was minimised as was data transmission propogation. Less obvious was that a shorter mission time would also tie up staff for a shorter duration. The next window would be around two years away, a diagram in the next section shows the best dates. To miss this particular opportunity might well have caused the US to be upstaged by the Soviet Union which after the shocks of Sputnik and Gagarin's manned orbit might cause a huge loss of prestige at a time when Communism was pressing forward (both politically and militarily) on many fronts. So the money and human effort was spent. I have never heard any reports of people complaining about the pressure they were under but I supposed when you are given a brand new bunch of scientific toys with almost unlimited money you just go with the flow, I know I would have!

One of the unseen background processes of spaceflight missions is that of TDA (Tracking and Data Acquisition), without effective capability the whole mission might be pointless. The launch process was monitored by AFETR (Air Force Eastern Test Range, Cape Canaveral) until the spacecraft settled into its outbound trajectory, AFETR was also supported by sub-stations in locations such as Bermuda and Carnarvon. Once on track Marina 4 was monitored and controlled from the DSN (deep space network) which is a series of radio telescopes positioned at convenient points around the world so that the spacecraft could be kept in radio view whilst the Earth rotates. The spacecraft carried a 10Watt radio transmitter. On arrival at an Earth telescope, e.g. the 85ft diameter Goldstone (pictured below), the received signal strength had attenuated to a mere 1 quintillionth (10^{-18}) of a Watt. Depending on other missions in process there was no guarantee that 100% of time could be allocated to this specific mission, indeed during one period the DSN was also tracking the (much shorter) Ranger 8 and 9 lunar missions. Further detail is available within NASA technical memorandum 33-329.

Figure 1: Goldstone radio telescope

Other key radio telescopes in the DSN were at Woomera (Australia) and Johannesburgh, there were also numerous subsidiary facilties in operation. Each DSN site was linked to the SFOF (spaceflight operations facility) at JPL Pasadena where overall mission management was based. Throughout the flight Mariner transmitted spacecraft engineering and systems status data back to Earth, at a few key events engineers transmitted commands to it. Data was transmitted from each DSN receiving station to SFOF by a mixture of telephony, telex and data network, since much data at the time would have been on paper tape or telex this would have been a low speed analogue transmisison method (maybe 75bps), however the project report refers to this as a high speed data network, which for 1964 was probably appropriate. Key information would need to be sifted so as to isolate realtime mission critical event information from less critical science data which could be set aside for later processing. There was also some overlap, hence duplication of data acquisiation between the DSN stations which would need to be deduplicated when the data arrived at SFOF. Apart from the camera for Mars imaging, the spacecraft also a carried a variety other sensors: 1) cosmic dust detector; 2) cosmic-ray telescope; 3) ionization chamber; 4) magnetometer; 5) trapped radiation detector; 6) solar plasma probe and 7) occultation experiment. Therefore during the flight, when in what they refer to as “coast mode”, it could carry out useful science by measurement of space environmental changes such as solar flares, solar wind, cosmic ray particles and also, getting closer to the asteroid belt, the amount of cosmic dust. The bi-directional transmission also enabled engineers to measure transmission intervals and by using signal propogation delays and the doppler effect could get accurate distance and velocity measurements.

All system operations were controlled by a computer sequencer command subsystem which could process any of 29 direct command words or 3 quantitative word commands for mid-course maneuvers. The central computer and sequencer operated stored time-sequence commands using a 38.4 kHz synchronization frequency as a clocking reference. Temperature control was achieved through the use of adjustable louvers mounted on six of the electronics assemblies, multilayer insulating blankets, polished aluminum shields, and surface treatments.

Unlike the earlier Mariners headed for Venus, where the Sun intensity grew stronger as they got closer, the Mars Mariners required a larger solar cell array to take account of the fact that solar intensity and hence generated power dimished with distance, it carried in fact 28,224 cells. The mass of the spacecraft was 260.8kg, it was built from nearly 140,000 parts. Excluding the solar cell arrays and the antenna it stood about as tall as an adult.

The picture below shows the general spacecraft layout. The four grey solar cell panels, are clearly shown as is the gold antenna dish to the top which in flight is oriented to face the earth, with the solar array oriented to face the Sun. To the fore of the main body is seen the grey rocket thruster, this was used for in flight course trajectory corrections, in the official report (TR-32-882) it is referred to as the PIPS (post injection propulsion subsystem).

Figure 2: Mariner 4.

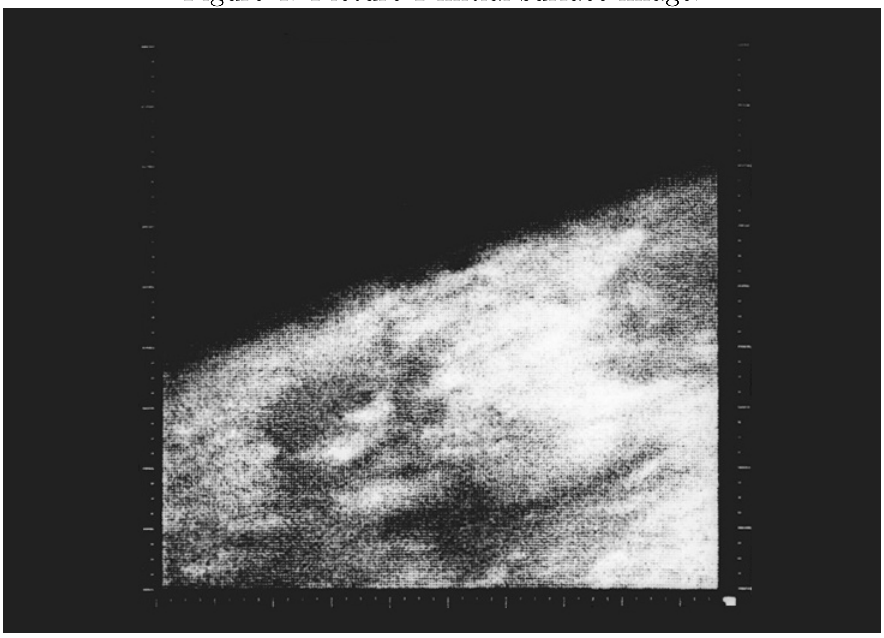
Available control commands that could be sent from Earth are shown in Appendix 1. Stored MT commands for automatic CCS activation are shown in Appendix 2.

So in visual terms from a human's point of view, the mission went from the initial launch, to delivering a number of Mars images, one of which follows.

Figure 3: Mariner 4 launch.

The black module towards the top is the adaptor module and the Agena, the spacecraft is hidden behind the aerodynamic shroud at the top.

Figure 4: Picture 1 initial surface image.

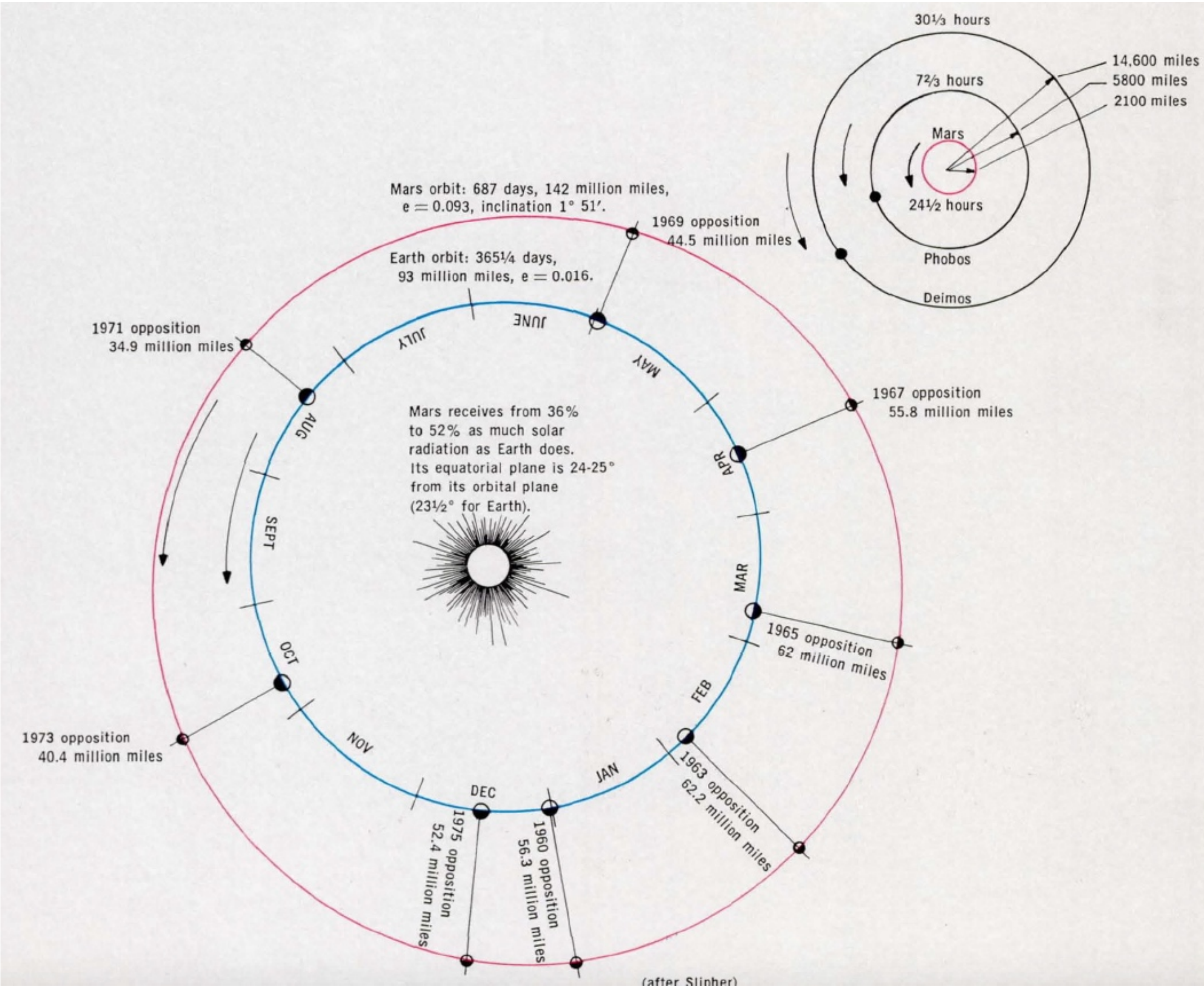


The surface image above is somewhat crude however, as will be seen later, there are numerous post processing techniques that can be used to bring up a far better image. If you look closely to the left you may see some haze, possibly atmospheric, which was later verified.

The flight plan

Any flight plan has to begin with the concept of from, to and distance. Since planets are in near circular elliptical motion around the Sun it makes sense to draw a map of when planets are the closest, referred to as "in opposition". The diagram below from NASA's Final Mission Report SP-139, shows the dates and time when Earth and Mars at closest, since they orbit at different velocities this only occurs approximatly once ever two years, the period that concerns us lies in the lower right quadrant of the diagram. To the top right the orbital parameters of the Martian system are shown.

Figure 5: Mars and Earth opposition dates.

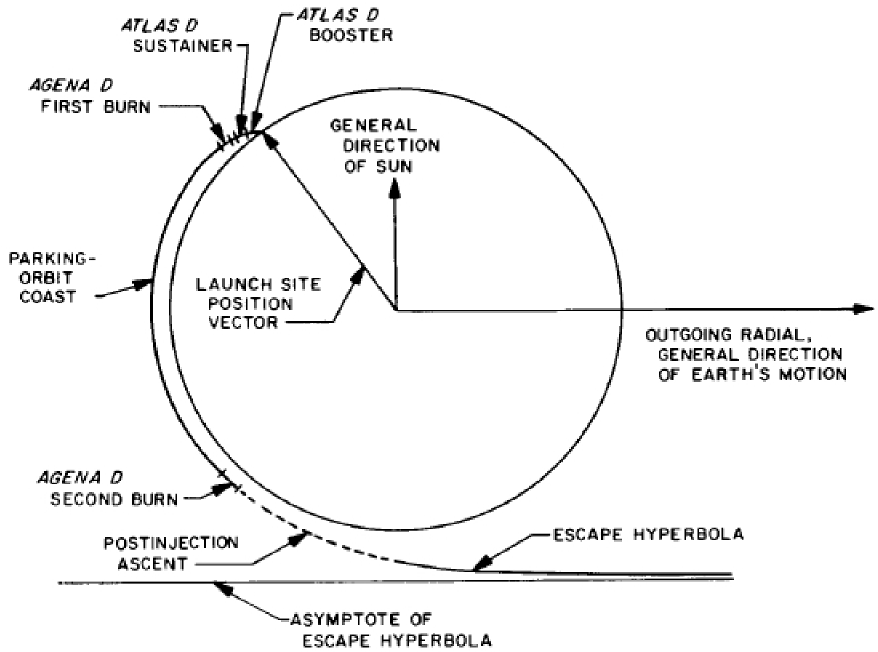


I apologise for the lost image quality caused by scaling, however the upside it that it shows information from an original source.

Using the ideas from above a flight plan involving thousands of orbital calculations was devised in order to meet the 1965 opposition opportunity. Marina 4 was launched from Earth by an Atlas booster on 28th November 1964. It was then boosted out of Earth orbit by a smaller Agena 4 booster into a hyperbolic escape orbit which would give it a trajectory to join a heliocentric (Sun centred) orbit. This heliocentric orbit was precisely planned and timed so that it would intersect closely with the natural path of Mars. At a point where the gravity of Mars was greater than that of the Sun the spacecraft would fall into a hyperbolic Martian orbit for a close flyby of Mars. In this time of space exploration the boosters did not have sufficient power to also carry the mass of any additional engine and fuel that would have been required to slow to attain a Martian orbit. Equally just achieving a close flyby was a very major navigational and planning achievement for the time, a sentence in a report says something like " Imagine trying to hit a snooker ball 400 miles away", the writer failed to mention that the ball would also be moving. After the Martian imaging encounter the spacecraft would switch back to it's collection of scientific sensors and resume sending data back to Earth.

The diagram below shows the sequence of Atlas launch and Agena orbital burns, all of which were precisely timed to align with the asymptote of the planned escape hyperbolic orbital trajectory. After the Agena's 2nd burn the spacecraft was effectively coasting under the diminishing gravity of the Earth to a point where the Sun's gravity was greatest.

Figure 6: Ascent from Earth.

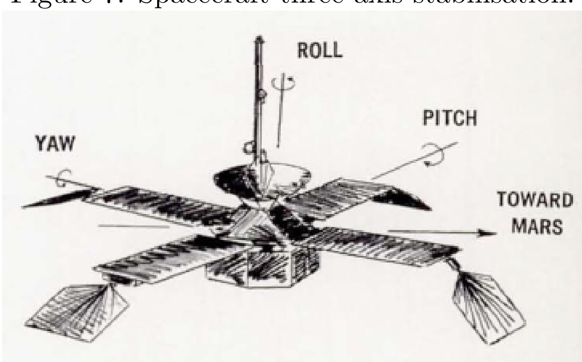


Once beyond the orbit of Earth Mariner 4 (and the previously failed Mariner 3) implemented the first stellar navigational instrument using both the Sun and Canopus for reference, which despite one quite significant glitch, described below, was successful. This was an essential part of the journey because for a lot of the time the Earth would be in shade. Therefore as we often see the Moon the spacecraft would only see an ellipse and even possibly even get the Moon and the Earth confused when Earth was mainly in shade. Oh yes and I should maybe add in here that it also takes 12 minutes for a radio signal to get from Mars to Earth, that is when they are close to each other. If they are on opposite sides of the Sun that time may increase by a factor of 3, in todays world imagine a one way (simplex) signal taking 12mins just to make your drone do something.

This extract explains very nicely the challenges of stellar navigation *"Mariner Mars was the first space mission using or needing a star as a reference object; earlier missions, remaining near Earth or traveling to Venus, had sighted on the home planet. But during this flight, Earth would transit across the face of the Sun, and through much of the flight it would appear as a relatively dim crescent. A bright reference source, at a wide angle away from the Sun, was necessary. Canopus filled the requirements for such a reference source. Mariner's Canopus sensor is mounted on the shady side of the spacecraft ring, pointing outward at an angle, so that its field of view covers an area in the shape of a shallow cone. An electronic logic in the attitude-control system was set to respond to any object more than one-eighth as bright as Canopus. Including Canopus, there were eight such objects visible to the sensor as Mariner swung around in the search mode; it was no surprise when the system acquired one of the other seven. The engineers had prepared brightness charts, corresponding to star maps of the ribbon of sky the star tracker would inspect, and the stars were recognized as they came around. It took more than a day of star-hopping to find Canopus".*

For navigation and TDA to be successful the spacecraft had to do two things, firstly keep the antenna oriented toward the Earth and secondly keep the navigation system firmly fixed on both the Sun and Canopus. In order to do this the spacecraft had to be three axis gyro stabilised and used cold gas jets for attitude adjustment. To avoid excessive gas usage, solar wind acting on the adjustable outer portions of the four solar cell array panels was also used. It was calculated that solar wind pressure contributed about 10,000 mile to the whole journey, very negligible.

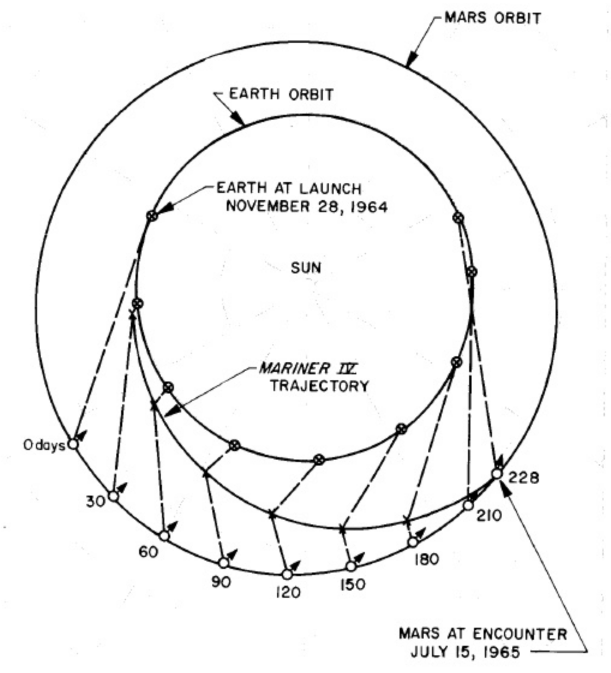
Figure 7: Spacecraft three axis stabilisation.



There was one course correction. From the report *"After about a week of tracking to determine the flight path and Mars arrival time, the thrust maneuver was scheduled for December 4. All the necessary ground commands had been received by the spacecraft, when it suddenly lost lock with Canopus. Though Sun lock was not disturbed, the spacecraft had no roll reference from which to orient its rocket motor, and the maneuver had to be postponed by ground command until Canopus lock could be regained. Next day, the thrust maneuver was successfully carried out. Three quantitative commands from Earth had the CC&S store in its electronic memory the dimensions of the required maneuver, which were a negative pitch turn of 39.16 degrees, a positive roll turn of 156.08 degrees, and a thrusting time of 20.07 seconds. Then three direct commands told the spacecraft to cock the system, take off the electrical safety catch, and ignite the engine. Since the motor was initially pointed almost along the direction of flight, the turns aimed it back in the general direction of Earth but high above the plane of the orbit. The pitch and roll were performed with better than 1 per cent accuracy, the velocity change with about $2\frac{1}{2}$ per cent accuracy. As planned, the angle of flight was changed less than $\frac{1}{4}$, degree, and the velocity was increased a little more than 37 miles per hour. Mariner was headed straight for its target, which was 7 months and 300,000,000 miles ahead."* Please note that Mars was not 300,000,000 miles away "straight ahead", this distance refers to the heliocentric orbit path travelled. Upon arrival near Mars it entered a hyperbolic arrival trajectory for a close flyby (it did not carry fuel to slow down into a Martian orbit).

The overall route of the spacecraft with respect to the planetary positions of Earth and Mars is shown below. This image is taken from the Final Project Report SP-139 and clearly demonstrates that the orbit of Earth takes less time that of Mars.

Figure 8: Spacecraft trajectory and planetary positions.



A signal was sent from Earth to switch planetary science mode on at 15:41:49 UT on July 14 1965. The camera sequence started at 00:18:36 UT on July 15 and 21 pictures using alternate red and green filters, plus 21 lines of a 22nd picture were taken. The images covered a discontinuous swath of Mars starting near 40^0 N, 170^0 E, down to about 35^0 S, 200^0 E, and then across to the terminator at $50^0 S$, 255^0 E, representing about 1% of the planet's surface.

The spacecraft's orbit took it behind the path of Mars at a closest altitude of 6,118 miles, the diameter of Mars is about 2,100 miles. After the camera sequence stopped it went back into science mode and continued transmitting data as part of an occultation experiment which amongst other things was transmitting data back to Earth through the thin Martian atmosphere.

NASA maintained contact with the spacecraft until 1 October 1965, when the probe was 309 million kilometers from Earth, the signal became too weak to discern any useful data from the carrier wave. Two years later, in October 1967, the spacecraft was reactivated for attitude control tests in support of the Mariner 5 mission to Venus, which used a similar spacecraft bus. Contact was finally lost on 21 December 1967.

The television camera and data storage

The imaging of the surface was effectively a process in collecting refelected sunlight from the surface, simplistically without allow for curvature image that flat areas would reflect sunlight at around 90^0 therefore the image would be brighter than say that of the edge of a crater where the reflected light may be at say 45^0, resulting in weaker luminosity, or areas in the shade, some of which might have been in total darkness.

The TV subsystem consisted of a Cassegrain narrow-angle reflecting telescope with a 30.5cm effective focal length and a 1.05 by 1.05deg field of view. This combined with a shutter and filter assembly that had 0.08 and 0.20s exposure times and alternately used red and green filters. The resultant image was sent to a slow scan vidicon tube, with a 0.22 by 0.22in. sq target, which translated the optical image into an electrical video signal, which was then sent to the electronics package including a TV data encoder. The output video signal is sampled at twice the maximum video frequency or 13.9 kHz for digital encoding.To minimize quantization noise, approximately 64 distinct video levels must be recognized by the encoder. A six-bit word length is sufficient to encode the videoamplitude to this degree of accuracy. As each TV line was scanned the amplitude of the analogue optical signal was assigned a value which represented each picture element (pixel) with a value in the range of 0-63 representing a greyscale from white to black, these were referred to as DN's (data numbers). On July 14, 1965, at 00:18 UT, the picture recording sequence commenced. Vidicon output underwent analog-to-digital conversion and the data was stored at 240,000 bits per picture (each picture was 200 lines by 200 pixels, 6 bits per pixel)on a two-track, 1/4in., 330ft long, magnetic tape loop on the spacecraft. Two of every three pictures taken were recorded on the tape, resulting in a chain of pairs of overlapping, alternately filtered pictures extending across the disk of Mars. The process yielded 21 pictures plus 21 lines of picture 22, which were written directly onto the on-board tape recorder.

Figure 9: TV camera assembly with telescope and filter.

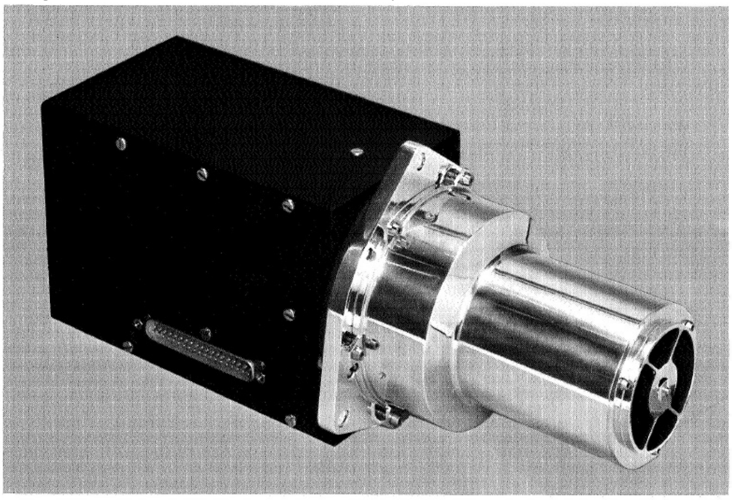


Fig. B-1. Television camera head

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The picture taking sequence lasted 25mins and 12 secs, so for a total of 21 complete pictures that was just over 1.2 minutes for each, from this each of the 200 scan lines for each picture took around 24 seconds, since each line had 200 elements each element had an exposure time of something like 0.1 secs. That was some seriously slow TV work and perhaps might be compared with the much faster moving images from Apollo 11 as an example of how technology had moved on and also bear in mind that the signal attentuation across the shorter distance from the Moon was much lower thus allowing a higher data rate. Each picture was roughly of an area of about 28,000 square miles (170 x 170miles) and this was stored on 200 x 200 pixels, therefore each pixel recorded the average luminosity of an area in the region of 7 square miles.The overall process meant that tape recorder retained about of 5.2 million bits of data for later transmission. In modern terminology that is a mere 612Kbytes, which we might well compare with the 360Kbyte floppy drives from the first personal computers of the early 1980's.

The data transmission

At 02:19:11 UT Mariner 4 passed behind Mars as seen from Earth and the radio signal ceased. The signal was reacquired at 03:13:04 UT when the spacecraft reappeared. Cruise mode was then re-established. Transmission of the taped images to Earth began about 8.5 hours after signal reacquisition and continued until August 3. All images were transmitted twice to ensure no data was missing or corrupt.

Telecommunications equipment consisted of a dual, S-band 7W triode cavity amp/10W TWTA transmitter and a single receiver which could send and receive data via the low- and high-gain antennas at $8\frac{1}{3}$ or $33\frac{1}{3}$ bps.

Data was continuously transmitted after planetary occultation of the spacecraft, by the radio subsystem from July 15 to 24, 1965, and was processed in real time by an IBM 7044/7094 system to format magnetic tapes of the image data for further processing by the existing Ranger (lunar) image processing programs and for conversion to a film record. Computer processing programs yielded images with greater contrast than the original raw image data. A detailed description of the television experiment, data processing, and the various versions of the photography can be found in the JPL "Mariner Mars 1964 Project Report, Television Experiment, Part I, Investigators' Report," of the Mariner IV Pictures of Mars, TR 32-884, 1967.

For anyone to make any sense of a datastream it is usefulto package it up with various labels and identifiers, to identify correct types and, sequences. The transmission from Mariner was without any protocol, error correction or parity bits, it was up to the people at SFOF to make sense of and interpolate any missing parts and to re-order any out of sequence data. It is therefore quite useful to take a look at the transmitted data formats that were used for the mission. There were three distinct data block layouts designated for transmission. For simplification of computing the identity of black types they had a standard lengh of 1281 bits. Using a standard size for each data block would have minimised processing cycles and in assembler language made it easier to perform bit pattern mask identification processing to call type specific programmed sequences.

As the data came in, via the DSN station network, it was locally stored, transmitted, processed and recorded in realtime to SFOF into an IBM 7044 computer, the printed data below is just a portion of the quantised data from picture number 4 showing just lines 100 to 110 with only the first 12 out of 200 DN values for each line. It would appear that lines 101-103 all had the same data number of 63 for each element and were marked as FONEY in HHMMSS column, instead of being given a received time stamp. If however we look at the column for element 1 on each of lines 100-106 the DNs go 40,63,63,63,40,40, since 101-103 are FONEY it might be reasonable to interpret their actual values to be closer to or even 40. This topic of image correction and enhancement is expanded in the next section.

Figure 10: Realtime print of received data.

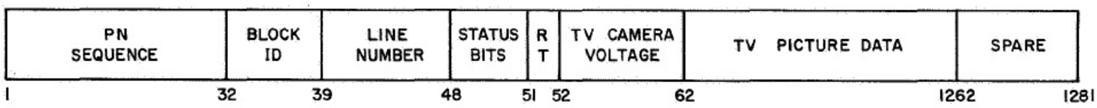
MARINER 64 ENCOUNTER PLAYBACK DATA --- JPEDIT PICTURE NUMBER 4

ELEMENT MATRIX A, GENERAL DATA AND ELEMENTS 1 THRU 20

HHMMSS	BITNO	D	S	LNO	R.	APER AAC FS SIGL	VLTG	1	2	3	4	5	6	7	8	9	10	11	12
005401	164983	2	2	100	0	0 001--0269.00	-.00	40	61	62	63	62	62	62	62	62	62	62	62
FONEY	-0-0-0			101-0		-0---0--0 -.00	-.00	63	63	63	63	63	63	63	63	63	63	63	63
FONEY	-0-0-0			102-0		-0---0--0 -.00	-.00	63	63	63	63	63	63	63	63	63	63	63	63
FONEY	-0-0-0			103-C		0---0--0 -.00	-.00	63	63	63	63	63	63	63	63	63	63	63	63
010410	169693	2	2	104	0	0 001--0269.00	-.00	40	61	62	63	62	62	62	62	62	62	62	62
010705	170976	2	2	105	1	0---0 01 .00	289.00	40	61	62	63	62	62	62	62	62	62	62	62
010940	172258	2	2	106	0	0 001--0269.00	-.00	40	61	62	63	62	62	62	62	62	62	62	62
011207	173541	2	2	107	0	0---0 01 .00	289.00	41	61	62	63	62	62	62	62	62	62	62	62
011502	174823	2	2	108	0	0 001--0269.00	-.00	40	61	62	63	62	62	62	62	62	62	62	62
011714	176106	2	2	109	0	0---0 01 .00	289.00	41	61	62	63	62	62	62	62	62	62	62	62
012000	177388	2	2	110	0	0 001--0269.00	-.00	41	61	62	63	62	62	62	62	62	62	62	62

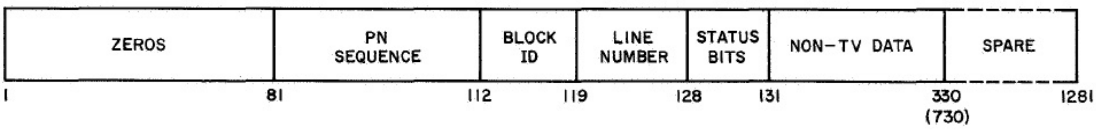
The type A data block was reserved for image transmission and began with a pseudonoise set of 31 bits, followed by a 7 bit binary coded number to identify block. This was essential for type recongnition, sequencing and also to know if blocks had been lost or corrupted. The next 9 bits identified the line number, followed by 3 status/exposure bits. One bit signified whether it was realtime data (for processing priority). The next ten bits, 52-62, were camera voltage values and bits 62-1262 (1,200 bits) were the 200 6bit data numbers generated for this line. Finally bits 1262-1281 were unused.

Figure 11: Type A data block.



The type B and C data block was reserved fornon image data (engineering and science) transmission and began with a set of 80 bits set to zero, followed by a pseudonoise set of 31 bits followed by bits 112-119 which were a 7 bit binary coded number to identify the block. Then followed 3 status bits. For type B block bits 131-330, these 200 bits were the actaul data. Bits 330-1280 were just padding to conform to the standard 1281 blong length. Type C blocks were as type B except the data was 600 bits from 131-730, followed by padding to the standard 1281 length was from bits 330-1281.

Figure 12: Type B and C data block.



Unlike a modern communication protocol there could be no synchronisation or re-transmission. Firstly the round trip signal delay would have been 24 minutes or more, secondly the data was not stored in a memory so to resend would have involved stopping the complete process and re-winding the tape back to an earlier point and then restarting. Since there would inevitably be some errors stopping and rewinding the tape repetitively may have damaged the tape and thus totally destroyed the experiment. It was therefore decided to transmit the data twice, then compare after processing and effectively fix any errors manually, or by programmed techniques. The whole two transmissions of the images took 9 days (for just 1,224Kbytes, or a total of 1.2Mbytes, this duration also includes transmission of around 2hours worth of engineering and scientific data between each image.

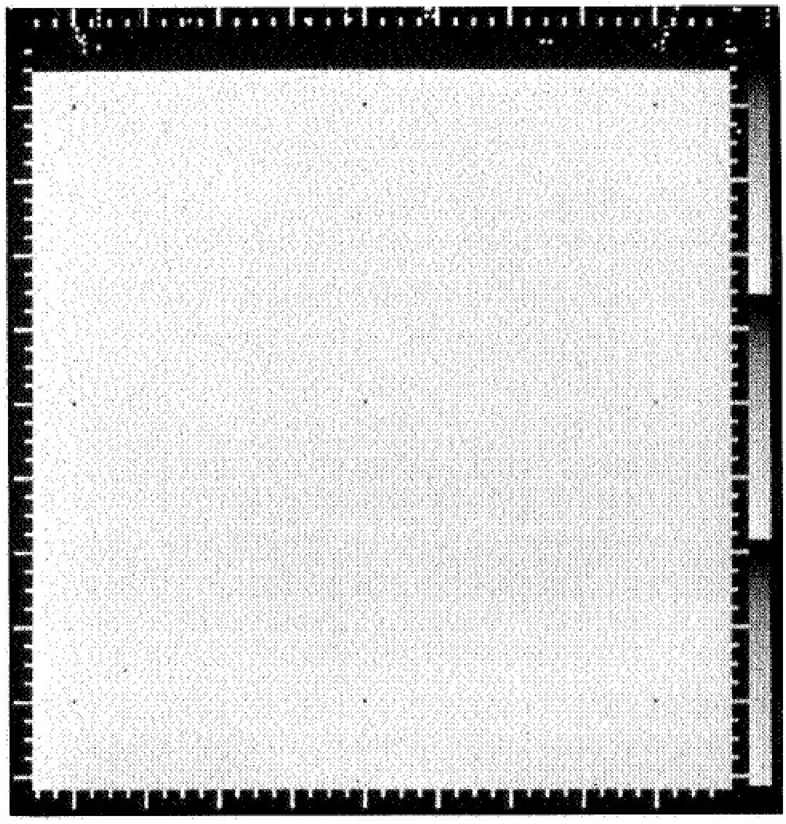
The actual image received for each picture, if printed out would have been 200 lines of 200 elements (a matrix of 4,000 elements), with each element being a data number DN in range of 0 to 63. Assuming a line printer could print 66 lines and maybe 160 characters we are probably looking at around 12 pages of printout per image. In their haste people at SFOF took initial data cut it into strips and painted shades of brown, orange and yellow onto each DN value, they got the following image.

Figure 13: Initial hand rendered image.

Image post processing

In the previous section a small section of the data for picture 4 was shown, immediately obvious damage or corruption was removed by the process of line averaging where the average of vertical elements below and above the suspect element would be used as a replacement of the suspect element's DN, where several adjacent elements were suspect then a process of interpolation could be used. Data could also be compared from the 1st and 2nd play backs and more realistic values substituted. The actual image display of this data in grayscale follows.

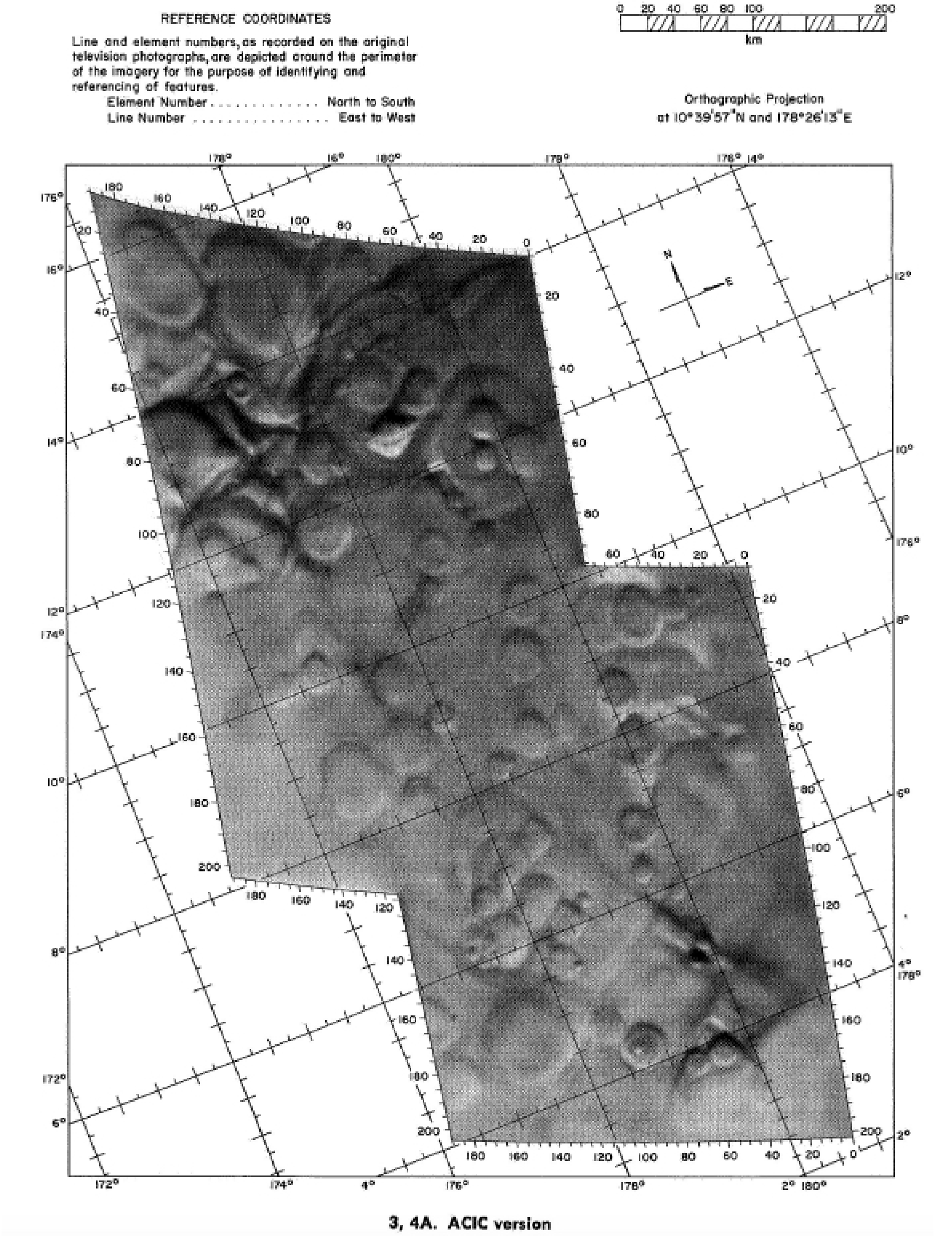
Figure 14: Unprocessed image of picture 4.



Picture 4

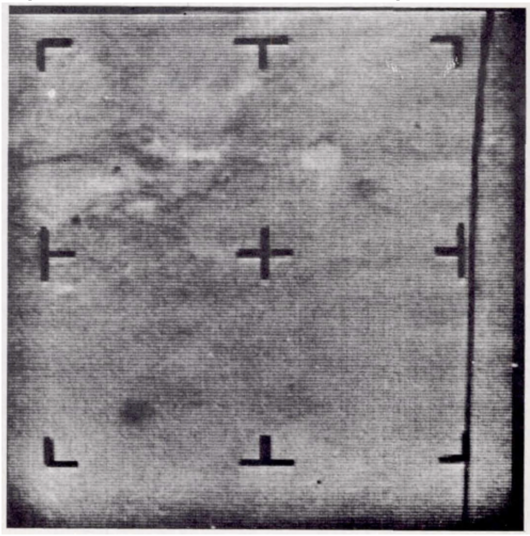
Clearly this does not immediately show us much, but by taking time and looking closer we can make out some areas of contrast. Bear in mind that each pixel represents around 7 sq miles. The question is how did they get from that to the next image, a decent combination of pictures 3 and 4 with some useful 3D perspective?

Figure 15: Processed combined images of picture 3 and 4.



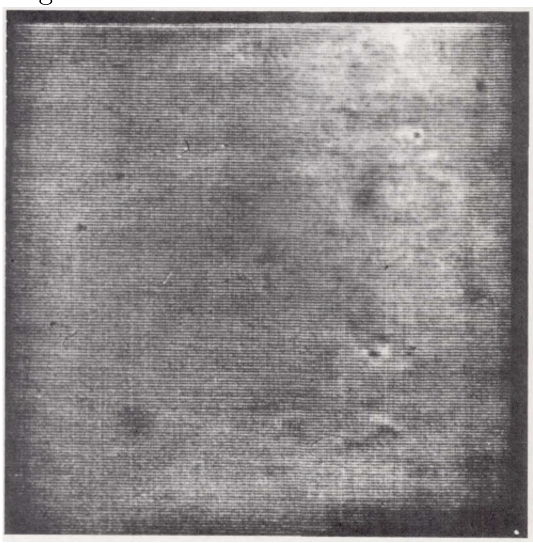
The above picture was a result of further combination of the images below of pictures 3 and 4 after initial processing, the bottom right of picture was positioned to over the top left of picture 4.

Figure 16: Picture 3 taken via green filter.



The contrast enhancement factor of the green filter was 5.

Figure 17: Picture 4 taken via red filter.



The contrast enhancement factor of the red filter was 3.

From 32-884 *"The first and second playbacks were merged, and the bad lines were eliminated. Discrepancies between individual pictures were repaired by hand rather than by computer. Because the percentage of bit errors was very small and the scene itself was one of low contrast, the errors that did exist were easily identified and corrected in most instances. This was done by fitting the erroneous point to the surrounding scene by correcting one of the 6 bits in the intensity word. A similar averaging technique was used to remove the black fiducial marks. The fiducial marks provided a means of rectifying the* *geometry in the pictures. Before launch, the geometric distortions of the camera and optical systems were recorded by photographing a grid pattern and noting its relationship to the fiducial marks. The geometric distortions in the Mariner IV pictures were not great, but were sufficient that in the application of calibration data it was necessary first to remove the small amount of nonlinearity that did exist. Thus, by using digital computer operations, geometric fidelity was achieved. Calibration data could then be incorporated. The major correction to the data was compensation for shading on the vidicon due to varying sensitivities over the photoconductive surface. Because the pictures were of very low contrast, the shading corrections became extremely important, even though the vidicon shading was not great. The shading corrections were made by using a large number of calibration frames. These frames were obtained by exposing the camera to a uniform scene whose illuminance had been accurately measured and was varied over the dynamic range of the systems. From this set of calibration frames, a calibration matrix was constructed to give the intensity corresponding to a given data number and gain setting for each of the 40,000 positions of the picture elements. This extensive process increased confidence in the stability and photometric accuracy of the vidicon system".*

For those readers with in depth imaging skills and higher mathematics the best source that I have found is document 32-884 which is over 170 pages of image data and an explanation of the pre and post flight calibration techniques carried out and the mathematics used. It is within there you will find many answers to the question that I posed earlier.

Summary

The emotional result was a initially a bit of a disappointment for many! Martians had not been found and the surface of Mars was not only as dead as the Moon but also very cratered and looked like the Moon. However despite the limitations of the vehicle itself a huge amount of planetary data could be derived for the sensors on board, so in scientific terms it still gave enough to justify further exploration.

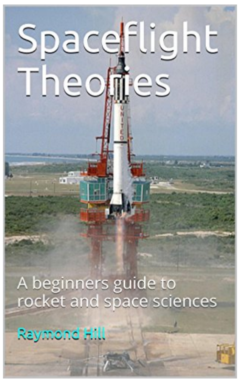
The total cost of the Mariner 4 mission is estimated at $83.2 million. Total research, development, launch, and support costs for the Mariner series of spacecraft (Mariners 1 through 10) was approximately $554 million. This must be viewed in monetary purchasing power of the 1960's. It was a massive investment and also carried out in the backdrop in which key scientific advances were being made across many fields almost on a quarterly basis. It was also, of course, carried out in the back drop of the Space Race during the Cold War and the USA were certainly not going let the USSR be seen to maintain superiority in anything for very long.

All experiments operated successfully with the exception of the ionization chamber/Geiger counter which failed in February, 1965 and the plasma probe, which had its performance degraded by a resistor failure on 6 December 1964. The images returned showed a Moon-like cratered terrain (which later missions showed was not typical for Mars, but only for the more ancient region imaged by Mariner 4). A surface atmospheric pressure of 4.1 to 7.0 mb and daytime temperatures of -100 degrees C were estimated and no magnetic field was detected, leading to the conclusion that the solar wind may have direct interaction with the martian atmosphere, and that the atmosphere and surface are fully exposed to solar and cosmic radiation.

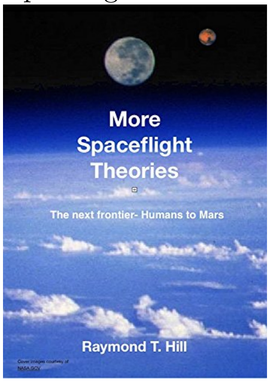
In addition to providing key information about how to enetually deliver future missions to the Mars, the spacecraft far outlasted its planned eight-month mission. It lasted about three years in solar orbit, continuing long-term studies of the solar wind and making coordinated measurements with the Mariner 5 spacecraft.

I hope you have found this mission precis of interest. There is far more information to be found on NASA and JPLs websites. If you want to know more about the fundamentals of space technology, which is of a moderate scientific and mathematical nature then I do have some e-books, details follow, which are available on Amazon.

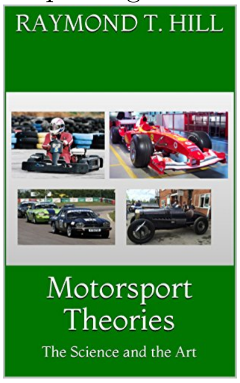
Please click on the required image, if you do wish to purchase any of these, you will need to navigate from this US site to your national Amazon site, they are free to Amazon Prime subscribers.



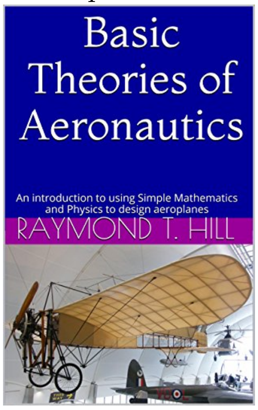
Spaceflight Theories



More Spaceflight Theories



Motorsport Theories



Basic Theories of Aeronautics

Appendix 1 - Earth initiated spacecraft control commands

Table 3–IV.—Ground commands

Command designation	Function	Effect
DC-1	Command data mode 1	Transfers data encoder to data mode 1 (engineering words) as soon as transfer is acceptable to the data encoder transfer logic
DC-2	Command data mode 2, turn on cruise science	Transfers data encoder to data mode 2 (20 engineering words, 40 science words) as soon as transfer is acceptable to the data encoder transfer logic. Applies 2400-Hz power to cruise-science instruments
DC-3	Command data mode 3	Transfers data encoder to data mode 3 (science words) as soon as transfer is acceptable to the data encoder transfer logic
DC-4	Command data mode 4	Transfers data encoder to data mode 4/data mode 1 (television picture data/engineering words) as soon as transfer is acceptable to the data encoder transfer logic. (If television picture data are available from video-storage subsystem, they are telemetered; if no such data are present, as between pictures, then engineering data are telemetered.) Removes 2400-Hz power from cruise-science instruments
DC-5	Switch data rates	Transfers data encoder (operating at either 8⅓ or 33⅓ bits/sec) from one bit rate to the other
DC-6	Switch analog-to-digital converter/pseudonoise generators	Transfers data encoder (with 2 such items: *A* and *B*) from one analog-to-digital converter/pseudonoise generator to the other
DC-7	Switch power amplifiers	Transfers radio (with 2 amplifiers: traveling-wave-tube *A*, and cavity *B*) from one power amplifier to the other
DC-8	Switch exciters	Transfers radio (with 2 exciters: *A* and *B*) from one exciter to the other
DC-9	Switch ranging	Transfers spacecraft radio ranging receiver (with 2 positions: on and off) from one position to the other
DC-10	Transmit high, receive low	Causes radio circulator switches to be conditioned so that spacecraft transmits on high-gain antenna and receives on low-gain antenna
DC-11	Transmit high, receive high	Causes radio circulator switches to be conditioned so that spacecraft transmits and receives on high-gain antenna
DC-12	Transmit low, receive low	Causes radio circulator switches to be conditioned so that spacecraft transmits and receives on low-gain antenna
DC-13	Inhibit maneuver command, inhibit propulsion command	Removes attitude-control excitation power from CC&S control lines so that attitude-control functions controlled by CC&S are disabled. Prevents pyrotechnics control circuitry from firing motor start and stop squibs

Table 3–IV.—Ground commands—*Continued*

Command designation	Function	Effect
DC–14	Remove maneuver command inhibit	Reverses state of all relays acted upon by DC–13. Returns attitude-control and pyrotechnics subsystems to CC&S control
DC–15	Canopus gate inhibit override	Causes Canopus sensor roll error signal to be applied to roll gas jet electronics at all times whether or not roll acquisition logic is satisfied. Prevents roll search signal from being applied to roll channel and prevents roll acquisition logic violations from turning on the gyros
DC–16	Narrow-angle acquisition	Initiates narrow-angle acquisition signal, thereby conditioning data automation system logic to begin television picture-taking sequence and to transfer data encoder to data mode 3
DC–17	Cycle Canopus cone angle	Changes voltage on deflection plates of Canopus sensor's image dissector, causing step change in Canopus sensor cone angle
DC–18	Gyros on: inertial control, positive roll	Turns on gyros (in inertial mode) and Canopus sensor Sun shutter. Turns off Canopus sensor. Turns on turn command generator. Conditions attitude-control circuitry for commanded roll turns. (Succeeding DC–18 commands cause clockwise 2.25° roll turns)
DC–19	Gyros off: normal control	Serves as reset for DC–15, DC–18, and DC–20
DC–20	Remove roll control	Turns off Canopus sensor. Turns on Canopus sensor Sun shutter. Inhibits roll acquisition logic from turning on gyros
DC–21	Roll override: negative increment	Simulates Canopus acquisition logic violation. Turns on gyros. Applies negative roll search signal to roll gas jet electronics. Causes spacecraft to begin counterclockwise roll search to acquire a new target. (If preceded by a DC–18, causes a 2.25° counterclockwise roll turn by spacecraft)
DC–22	Change tracks	Changes video-storage-subsystem tape tracks by applying power to record head and gating output of playback amplifiers
DC–23	Arm second propulsion maneuver	Sets relays in pyrotechnics subsystem such that CC&S commands M–6 and M–7 are routed to squibs allotted to second motor burn
DC–24	Inhibit scan search	Removes 400-Hz single-phase power from scan platform drive motor
DC–25	Turn on planetary science, unlatch cover	Causes 2400-Hz power to be applied to encounter science loads, video storage subsystem, and cruise science loads (if 2400-Hz power was off to cruise science). At same time, applies 52 V dc from booster regulator to 400-Hz single-phase inverter, which in turn supplies power to scan system drive motor and video-storage-subsystem record motor.

Table 3-IV.—Ground commands—*Concluded*

Command designation	Function	Effect
		Enables battery charger boost mode. Causes pyrotechnics subsystem to energize solenoid that releases scan platform science cover
DC-26	Turn off planetary science, cruise science, and battery charger	Removes 2400-Hz power from all science loads (allowing video-storage-subsystem 2400-Hz power to remain on) and 52-V-dc power from 400-Hz single-phase inverter. Enables battery charger boost mode
DC-27	Initiate midcourse maneuver...........	Starts maneuver sequence by issuing CC&S command M-1 (turn on gyros), applying power to maneuver clock, and removing maneuver clamp and flip-flop reset signal from CC&S maneuver circuitry
DC-28	Turn on battery charger, turn off video storage subsystem	Removes 2400-Hz power from video storage subsystem. Enables charge mode of battery charger
DC-29	Arm first propulsion maneuver.........	Sets relays in pyrotechnics subsystem such that CC&S commands M-6 and M-7 are routed to squibs allotted to first motor burn
QC1-1	Command required pitch turn duration for maneuver	Sets pitch turn polarity and preloads CC&S pitch shift register such that, at a 1-pulse/sec counting rate, the register will fill in required time interval for attitude-control subsystem to pitch turn the spacecraft the amount required for a given midcourse maneuve
QC1-2	Command required roll turn duration for maneuver	Sets roll turn polarity and preloads CC&S roll shift register such that, at a 1-pulse/sec counting rate, the register will fill in required time interval for attitude-control subsystem to roll turn the spacecraft the amount required for a given midcourse maneuver
QC1-3	Command required motor burn duration for maneuver	Preloads CC&S velocity shift register such that, at a 20-pulse/sec counting rate, the register will fill in required time interval for a midcourse motor burn yielding required velocity change for a given midcourse maneuver

The three QC commands are for data sent from Earth to be stored on the CCS for later use.

Appendix 1 - CCS stored spacecraft control commands

Table 3–V.—Central computer and sequencer (CC&S) commands

Command designation	Function
L–1	Deploy solar panels, unlatch scan platform
L–2	Turn on attitude-control subsystem
L–3	Energize Canopus sensor, turn on solar pressure vanes
M–1 (set)	Gyros on, data encoder to data mode 1
M–1 (reset)	Gyros off, data encoder to data mode 2
M–2 (set)	Spacecraft on inertial control
M–2 (reset)	Spacecraft off inertial control (reacquire Sun and Canopus)
M–3 (set)	Turn polarity (set if positive)
M–3 (reset)	Turn polarity reset
M–4 (set)	Pitch-turn start
M–4 (reset)	Pitch-turn stop
M–5 (set)	Roll-turn start
M–5 (reset)	Roll-turn stop
M–6 (pulsed)	Ignite midcourse motor
M–7 (pulsed)	Turn off midcourse motor
MT–1 (set)	First Canopus sensor cone angle update
MT–2 (set)	Second Canopus sensor cone angle update
MT–3 (set)	Third Canopus sensor cone angle update
MT–4 (set)	Fourth Canopus sensor cone angle update
MT–5 (set)	Switch transmitter to high-gain antenna
MT–6 (set)	Switch data encoder bit rate to $8\frac{1}{3}$ bits/sec
MT–7 (set)	Encounter science on (all science on)
MT–8 (set)	Encounter science off (all science off)
MT–9 (set)	Cruise science off, start data playback
CY–1 (pulsed)	Backup switching for radio subsystem (pulse occurring every $66\frac{2}{3}$ hr)