SEARCHING FOR LIFE ON MARS:
THE DEVELOPMENT OF THE VIKING GCMS

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The Top Ten List

On October 26, 1971, Jim Martin of NASA's Langley Research Center added a new entry to his "Top Ten Problems" list for the Viking project, the first mission ever to attempt a soft landing on the surface of Mars. Viking had been in development formally for nearly three years when Martin, the project manager, determined that the configuration and schedule of one of the spacecraft's key scientific instruments belonged on the project's short list of critical problems.

Martin was known among his colleagues for a pragmatic, no-nonsense management style. He began the Viking Top Ten Problems list in the spring of 1970 to give problems that could possibly affect the launch date the proper degree of visibility and oversight. Viking Project Directive #7, issued more than a year later, stated: "It is the policy of the Viking Project Office that major problems will be clearly identified and immediately receive special management attention by the establishment of the Top Ten Problems list." To make the list, a problem had to have a serious impact on "the successful attainment of established scientific and/or technical requirements, and/or the meeting of critical project milestones, and/or the compliance with project fiscal constraints." Anyone associated with the Viking project could identify a potential priority problem by defining the exact nature of the difficulty and forming a plan and schedule for solving it. When Martin made an addition to his list, a person in the appropriate organization was charged with solving the problem, and someone in the Viking Project Office monitored his progress.

Like the manager of any highly complex spacecraft development project, Martin had a long list of problems from which to choose his top ten. By 1971 Viking's launch date had already been pushed back from 1973 to 1975 due to Congressional budget cuts. Two years after Neil Armstrong and Buzz Aldrin set foot on the moon, the Agency was stretched thin, having announced the elimination of 50,000 jobs. It didn't help that Viking was running well over initial planning estimates for the mission to Mars. (See Appendix 1, Figure 1-0.)

The Viking Mission

The technical challenges for Viking were no less daunting than the fiscal ones. Nobody had landed on Mars before, so the spacecraft itself required significant innovative technology. The opportunity to conduct experiments on the planet's surface led to an extremely ambitious scientific agenda featuring thirteen instruments that Martin struggled to keep within the constraints of the project. He had to manage the relationships among

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* Many details and all tables in the appendix of this case study have been adapted from the NASA History Office's account of the development of the GCMS in *On Mars: Exploration of the Red Planet 1958-1978*: <http://history.nasa.gov/SP-4212/ch6.html>; <http://history.nasa.gov/SP-4212/ch7.html>; <http://history.nasa.gov/SP-4212/ch8.html>

the scientists designing the experiments and the engineers developing the flight hardware to perform the experiments. If the project's scientific capabilities were pared down too far, the mission would not achieve its full potential. On the other hand, the instruments could not overwhelm the requirements for the spacecraft's mass as well as the project's cost and schedule. Martin had to strike a balance with a diverse group of highly accomplished experts, all of whom had strong opinions.

The primary objective of the Viking science mission was the stuff of dreams: to determine if there was evidence of life of Mars. Developing the instruments that would enable this analysis was not proving easy.

The Gas Chromatograph-Mass Spectrometer

The instrument causing Martin the most heartburn in October 1971 was the gas chromatograph-mass spectrometer (GCMS). The GCMS was actually two instruments – a gas chromatograph and a mass spectrometer – in one. Conducting gas chromatography and mass spectrometry in the laboratory was hard enough. In the early 1970s, building such an instrument as even a lab model required experts who could keep up with the latest developments in the field, since the science was changing on an almost-daily basis. The GCMS that Dr. Klaus Biemann, the leader of the molecular organic analysis team, had at MIT was the size of a room; its human operator could literally walk through it. Shrinking the instrument to a mass of less than 15 kg that could fit in a 1'x1'x1' box on a spacecraft, operate robotically, and survive the rigors of both the journey and the Martian atmosphere presented myriad challenges. At the time, the GCMS and the other Viking science experiments were the most difficult ones ever attempted by NASA.

A gas chromatograph uses a thin capillary fiber known as a column to separate different types of molecules, based on their chemical properties. Each type of molecule passes through the column at a different rate, resulting in each type emerging from the column in a defined sequence. The temperature of the column determines the rate of separation.

Once processed by the gas chromatograph, the molecules would then enter the mass spectrometer, which would evaluate and identify them by breaking each one into ionized fragments and detecting these fragments using their charge-to-mass ratio. This produced a unique profile of each compound that could be converted into a digital signal and transmitted to Earth

Used together, these two components would offer a much finer degree of substance identification than either unit used separately. Scientists considered the GCMS a gold standard for forensic substance identification because it performed a specific test. (A specific test positively identifies the actual presence of a particular substance in a given sample.) A working GCMS was absolutely critical to the organic analysis of the soil on Mars.

Jet Propulsion Laboratory

Martin had assigned the development of a GCMS prototype to the Jet Propulsion Laboratory (JPL) in August 1968. JPL had responsibility for developing, fabricating, and testing a lightweight portable “breadboard” (experimental model) of the GCMS before the selection of a contractor to build the flight hardware. JPL, a Federally Funded Research and Development Center (FFRDC) managed for NASA by the California Institute of Technology (Cal Tech), already had proven in-house expertise developing spaceflight hardware for planetary missions. In 1965, the *Mariner 4* spacecraft, a JPL effort, had made the first “fly-by” of Mars, taking close-up photographs of its surface. JPL was an institution with a rich spaceflight tradition, great technical depth, and a strong sense of pride in its in-house abilities.

Though Martin was 3000 miles from JPL in Langley, Virginia, this kind of a long-distance relationship was business as usual at NASA. Under the Agency’s decentralized structure, with its field centers spread out across the country, spaceflight hardware was routinely designed in multiple locations, built at contractor (and subcontractor) facilities, and then shipped and integrated at yet another location before being launched. Decentralization allowed the Agency to draw on professional communities of expertise that had grown up around a combination of government facilities and universities, much like JPL had emerged from Cal Tech in the late 1930s.

A Neglected Stepchild

In the case of the GCMS, though, the arrangement was not functioning as smoothly as Martin had expected. In September 1970, Cal Broome, who headed the working group in charge of overseeing Viking's scientific payloads, told Martin that the GCMS was a “stepchild” not getting proper supervision because of the decentralized management structure at JPL. Two weeks later, word came back that JPL had taken steps to strengthen its control of the project. The JPL team was confident that it possessed the in-house expertise to get the job done.

The changes at JPL did not result in the kind of progress that Martin wanted. In January 1971, a five-day GCMS engineering model review was a disaster, resulting in between 200 and 300 "request for action" forms. The instrument’s mass and cost both far exceeded earlier estimates. Two months later, the GCMS weighed in at about 14.5 kilograms, nearly 40% over its projected mass eighteen months earlier. (See Figure 1-1.) At the March Science Steering Group meeting, Martin indicated that funding increases, technical problems, and schedule slips were causing considerable concern about the future of the GCMS.

The picture was not entirely bleak. That same month, the GCMS breadboard operated for the first time as a completely automated soil-organic-analysis instrument. Several technical problems were encountered, but Martin and the Viking Project Office considered it a step forward. There was no question about the JPL team’s technical talent; its ability to deliver a working instrument in time for launch was another matter.

Meanwhile, an ad hoc GCMS requirements review panel, established by Martin after the disastrous review in January, met to discuss possible ways of simplifying the design. The ad hoc panel's preliminary results were presented at the June 1971 Science Steering Group meeting. Martin presented several concerns to the group: the start of GCMS science testing had slipped by six months (from early 1971 to October 1971); after years of work the breadboard was just ready; and at 14.5 kilograms the GCMS was now getting too heavy. The ad hoc panel presented five GCMS design variants with weight projections between 11 and 14 kilograms, but they requested (and were given) more time to study these alternatives.

Ongoing Concerns

Between the autumn of 1971 and the winter of 1972, there were numerous conversations between Viking Project Office personnel members and JPL authorities regarding the GCMS. Martin was not happy with JPL's management of the project. Viking's project scientists, who had years of research tied up in this development, did not hesitate to tell him that they too were displeased with the progress JPL had made.

Martin did not want the lab to build the GCMS; that was the responsibility of the flight hardware contractors. JPL's oversight of the contractors was a major source of concern. Beckman Instruments (gas chromatograph), Perkin-Elmer (mass spectrometer), and Litton Industries (data system) were building the individual components of an instrument that required the highest degree of integration, yet the three wouldn't even talk directly to one another, despite the fact that their respective facilities were within a fifty-mile radius in California. None had been designated as the prime contractor.

In October 1971, Martin considered finding another organization to handle the GCMS contract. The project office awarded Bendix Aerospace a contract to study the feasibility of using an organic analysis mass spectrometer (OAMS) in place of the GCMS. Later that month, when he added the GCMS to the Top Ten Problems list, he wrote, "Specifically the problem is the systems design and program redefinition of a simplified GCMS." It was a prelude to a more aggressive management approach.

At the February Science Steering Group meeting, a top scientist reported on the GCMS and OAMS, noting that both had advantages and disadvantages that could not be directly compared. That settled it for Martin. He decided in favor of continuing the development of a simplified version of the GCMS. He removed the GCMS from the Top Ten Problems list for the time being, knowing that in March he would take action to get the instrument on track.

(End of Part I)

SEARCHING FOR LIFE ON MARS: THE DEVELOPMENT OF THE VIKING GCMS* (CONCLUSION)

Martin decided to shift management of the GCMS from JPL to his Viking project office at Langley. According to cost projections, it would be cheaper by about $7.5 million to keep the GCMS project (rather than shifting to an OAMS) while transferring management of it to Langley.

This decision to take the GCMS project from JPL was not made lightly. JPL, though technically not a government institution, was an integral part of the NASA family and the Viking mission; it still had responsibility for designing and building the Viking orbiters, managing tracking and data acquisition through the Deep Space Network, and managing the Viking mission control and computing center. Martin knew his decision would cause rumblings.

Those considerations aside, Martin felt compelled to bring the project under the supervision of his own project team. He could handle the political fallout of his decision, but the prospect of launching the Viking spacecraft without a GCMS – an instrument that was critical in the search for signs of life on Mars – was unthinkable. Although its development and fabrication was still far from ensured, he was confident that the project office at Langley could bring some discipline to it. He sent Angelo "Gus" Guastaferro, Deputy Project Manager for Management, to California to novate the GCMS contract with JPL, and he appointed Joseph C. Moorman to manage the instrument.

Back in the Top Ten

Moorman, who had been managing a biology instrument prior to taking over the GCMS, did not have this kind of experience corralling contractors or shifting a project from one center of operations to another. The Viking project was the first in his NASA career, and the difficulties presented by the GCMS were an extraordinary challenge for even a very seasoned project manager.

Six months later, Martin had to reckon with the reality that Moorman had not brought the GCMS up to speed. This was not a routine science instrument; it required strong systems engineering and experienced project management. He put the GCMS back on the Top Ten Problems list, where it remained for more than two years until shortly before launch.

Beyond the Org Chart

By the end of 1972, Martin took action again. He reassigned Moorman and put his own deputy for management, Guastaferro, in charge of overseeing the instrument's development on a day-to-day basis. Martin did not care about Guastaferro's title; he needed a senior person who could take control of the project and the contractors.

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Guastaferro's first task was to establish a more productive and cooperative relationship among the contractors; his strategy was to shift from "inattention" to "over-attention." He left Langley and relocated to California for the next two years so he could shuttle among their facilities to monitor progress. He also assigned Litton Industries responsibility as the instrument's prime contractor, since its data system would ultimately integrate the information from the gas chromatograph and the mass spectrometer and send data back to Earth.

Reaching Out for Answers

Guastaferro relied extensively on Al Diaz, the GCMS chief engineer, to provide the technical expertise that the project required, since there were still significant problems to resolve. Guastaferro and Diaz sought help wherever they could find it, often reaching out to experts in private industry and academia for answers. On more than one occasion, they discovered that others had overcome similar technical issues, but the solutions were proprietary or classified.

One example involved a problem with electrical high-voltage arcing, which would ruin the instrument. The key to fixing this was developing an epoxy-like compound to insulate the circuitry from the conditions that made the instrument susceptible to arcing. The JPL team had never been able to devise the right formula. When Guastaferro and Diaz began to ask around, they discovered that a private industry contractor working for the Department of Defense had encountered this same issue with its own technology. While the representative of the contractor could not divulge the process to NASA, he told Guastaferro and Diaz to send him the component, and he would ensure that the problem disappeared. There were huge risks in making this handover – it was inconceivable that the JPL team would have taken this step – but Guastaferro and Diaz were more concerned with getting a working instrument to the launch pad on time than with ownership of the technical solution.

End Zone in Sight

There were dozens of technical issues to overcome, but one by one they were resolved. By the time of the GCMS critical design review (CDR) in mid-July 1973, there were only three major outstanding concerns, a vast improvement considering the previous difficulties with the instrument.

In May 1975, science payload manager Cal Broome advised Jim Martin that he could remove the GCMS from the Top Ten Problems list, which Martin did on June 6, 1975. Ten weeks later, *Viking I* was launched on August 20, 1975 from Cape Canaveral, Florida, followed by *Viking II* on September 9, 1975.

Appendix 1: Tables

Viking Cost Projections, 1974 (in millions)					
Date	Lander	Orbiter	Support	Total Estimated Cost at Completion (Estimated Total + APA [a])	Cumulative Total
July 1970 baseline	$359.8	$256.0	$134.2	$750.0 + $80.0 = $830.0	$ 51.0
Dec. 1970	359.8	256.0	134.2	750.0 + 80.0 = 830.0	54.5
June 1971	358.0	256.3	135.7	750.0 + 80.0 = 830.0	81.8
Jan. 1972	384.6	256.7	143.7	785.0 + 44.7 = 829.7	150.6
June 1972	414.4	252.3	134.5	801.2 + 28.2 = 829.4	223.8
Dec. 1972	426.1	251.3	132.2	809.6 + 19.8 = 829.4	366.6
June 1973	436.2	247.5	143.0	826.7 + 11.3 = 838.0	466.5
Dec. 1973	456.7	241.0	140.3	838.0 + 0.0 = 838.0	595.2
Mar. 1974	511.9	242.4	140.2	894.5 + 33.0 = 927.5	646.7
Apr. 1974	518.2	242.8	140.2	901.2 + 18.8 = 920.0	667.9
Dec. 1974	545.2	242.1	139.1	926.4 + 3.6 = 930.0	805.2
July 1975	548.7	243.0	138.0	926.2 + 3.5 = 929.7	855.2
July 1976	558.2	243.0	134.1	935.3 + 0.3 = 935.6	898.9
Jan. 1977 actual costs	558.2	240.5	115.8	972.4 [b]	914.5

[a] Allowance for program adjustment (APA), or reserve funds.

Figure 1-0: One year into its development, the GCMS was expected to comprise roughly one-third of the lander payload's total mass. (Source: NASA History Office)

Estimates for Viking Lander Payload, September 1969		
Item	Weight (kg)	Cost (millions)
Gas chromatograph-mass spectrometer	10.4	8.5
Total lander payload	31.7	$43.4

Figure 1-1: One year into its development, the GCMS was expected to comprise roughly one-third of the lander payload's total mass. (Source: NASA History Office)

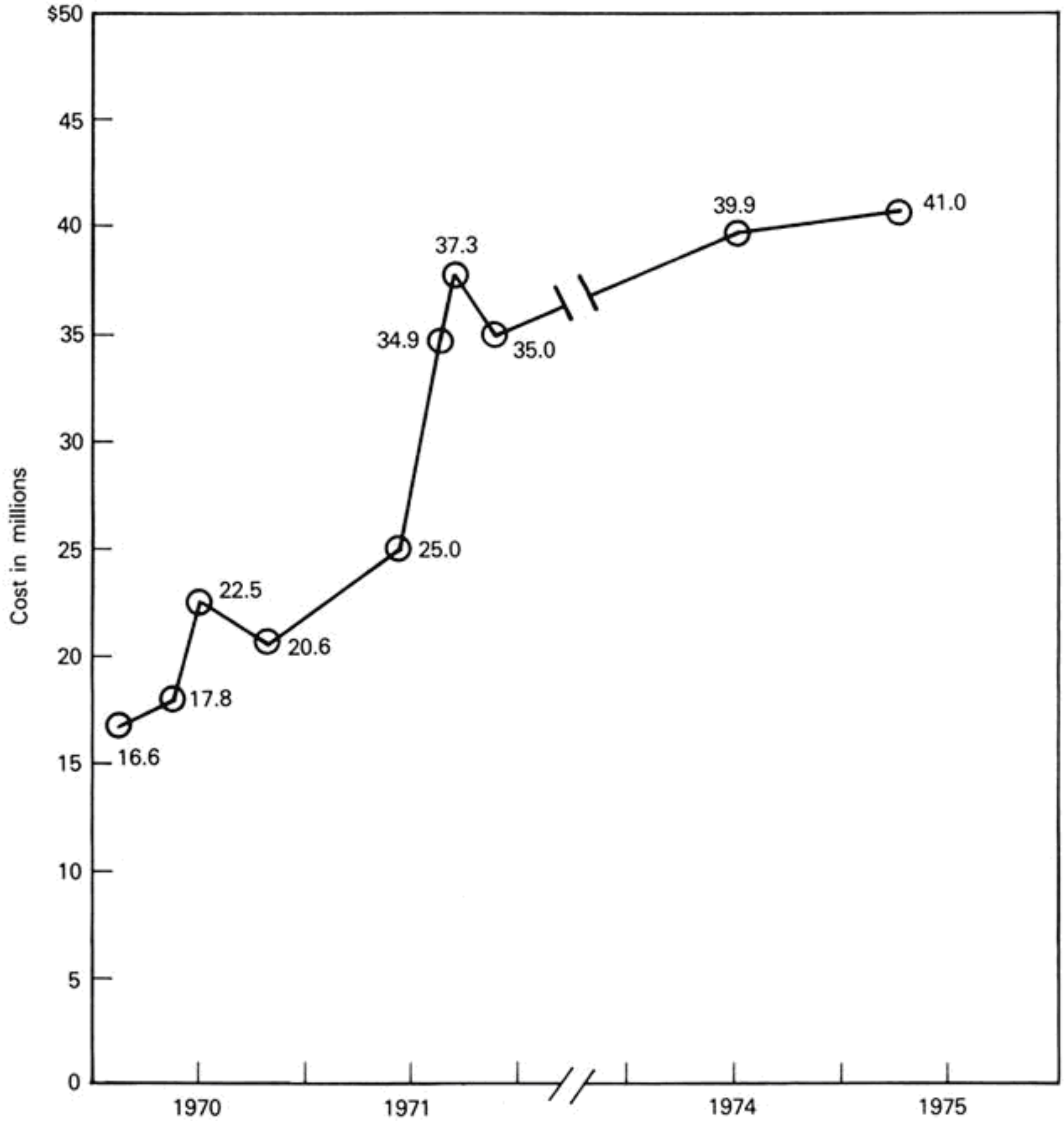

Figure 1-2: GCMS cost projections. (Source: NASA History Office)

Date	GCMS	Total Lander Estimate	Total Lander Actual Cost
3 June 1970	17.8	360	19
Sept. 1970	20.6	-	-
Aug. 1971	25.0	401	62
Feb. 1972	35.0	381	107
July 1972	35.0	420	149
Apr. 1973	35.4	430	286
Mar. 1974	38.7	512	411
July 1974	39.9	543	451
Sept. 1974	-	559	473
Mar. 1975	41.0	545	545
June 1976	41.2 [a]	-	553.2 [a]

Figure 1-3: GCMS and total lander cost projections. (Source: NASA History Office)

Appendix 2: Instructor's Notes

This case study has been designed to be delivered in two parts. Participants should be given Part I to read prior to in-class discussion, preferably as a homework assignment or "read-ahead" that allows ample time for analysis and reflection.

The instructor should then lead a guided discussion of Part I, focusing on the class's interpretation of the problem:

- What factors (organizational/managerial/technical/other) contributed to the lack of progress on the GCMS instrument?

- What were the key decisions points in the development of the GCMS?

- What could have been done differently up to this point in the case?

- What options did the project manager have to turn the situation around?

Participants should be encouraged to draw analogies to their own experience and develop as many options as possible. The exploration of Part I should take three-quarters of the allotted class time.

The instructor should then distribute Part II and allow the participants 5 minutes to read the real-life conclusion to the case. The concluding discussion should encourage participants to consider:

- What were the project manager's key decisions that led to the ultimate successful outcome of the case? How did he balance the pros and cons of those decisions?

- How did the management style of the team in Part II differ from the team in Part I?