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A Comparison of U.S. and Soviet Efforts to Explore Mars

U.S. effort remains minimal despite early success, Soviet effort remains large despite early failures.

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The year 1965 was a momentous one in the unmanned exploration of Mars. The U.S. spacecraft Mariner IV obtained 21 close-up pictures of that planet and successfully returned these and other scientific data to Earth. Earlier in the year, a larger Soviet spacecraft, Zond II, failed in flight after completing 61 percent of the journey—almost an exact repetition of the failure of the earlier Soviet spacecraft Mars I, launched 1 November 1962. The Soviets' determination to succeed in their efforts to explore Mars, despite such frustrations, was dramatically highlighted in July 1965 when Zond III was launched as a test shot for a subsequent Mars mission, presumably in 1967. Zond III successfully obtained pictures of the hidden back side of the Moon, extending the coverage of the 1959 Soviet photographic probe Lunik III. In a costly rehearsal for photography of Mars by later probes, Zond III has been repeatedly transmitting these lunar pictures as it continues out to rendezvous with an empty portion of the orbit of Mars.

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The American scientific community should, and evidently does, feel proud and gratified that the Mariner mission to Mars, through successful utilization of national resources, not only accomplished a remarkable technological feat but also discovered extraordinary new facts about Mars which were beyond the reach of earth-based instruments. Similarly, in the United States and elsewhere, there is widespread anticipation of the new information, pictorial and otherwise, to be returned by future U.S. and Soviet spacecraft of greatly increased capability.

However, several less well publicized aspects of the 1965 U.S. Mars program may be regarded as disappointing. Even though 1965 was the year of Mariner's great Mars success, it was also the year in which the final decision was made not to fly such spacecraft [500- to 600-pound (225- to 270-kilogram)] to Mars in 1967, and, by implication, ever again. In addition, 1965 was the year in which funds for a second-generation U.S. system (weighing 1500 pounds at Mars), roughly comparable in capability to the present Soviet system, were not requested during congressional authorization testimony, despite the high hopes and expectations expressed on that subject at similar hearings over the preceding 5 years.

Throughout most of 1965 a "test flight" past Mars in 1969 with a highly touted third-generation U.S. system (7000 to 10,000 pounds at Mars) was considered a possibility. Such a test flight was under consideration as a step to precede ambitious efforts to orbit and land payloads in 1971 and 1973. However, in October 1965 the entire third-generation concept was scrapped in favor of an even more ambitious approach—that of trying to fly a 30,000- to 70,000-pound system to Mars. It had been hoped that this venture, for which the launch vehicle would be the same as that to be used for the Apollo manned lunar landing, might be attempted in 1971 in preliminary form. In the closing days of 1965, NASA announced that this program will not be initiated before 1973, and that a minimal second-generation mission had been reinstated for the 1969 launch opportunity.

Data for all the attempts to explore Mars made, to date, by the United States and the U.S.S.R. are given in Table 1. The pattern is almost identical to the pattern for U.S. and Soviet attempts to explore Venus, as shown in Table 2. Two large Soviet spacecraft are now on trajectories toward Venus, despite six previous failures. The U.S. had abandoned new exploration efforts, after the initial success in 1962, until recently, when it was announced that the spare Mariner C spacecraft would be sent to Venus in 1967.

There is obviously a basic difference in priorities—hence, in distribution of resources—between the U.S. and the Soviet space programs. The Soviets have placed (and continue to place) much greater emphasis than the United States has upon unmanned exploration of the planets, in terms both of the absolute level of such effort and of the proportion of the total space effort devoted to it.

Nevertheless, a comparison of the efforts of the two countries to explore Mars is both valid and useful. The U.S. National Academy of Sciences and numerous other scientific groups have repeatedly assigned the exploration of Mars highest priority in the planetary program. This emphasis culminated in an October 1964 statement of the Space Science Board (*1*):

> The primary goal of the national space program in the exploration of the planets is Mars: it is one of the nearer planets (and hence relatively accessible); as a planet, its biological, physical, chemical, geophysical, and geological properties are at least as interesting as those of any of the other planets; of even greater significance and excitement to mankind, it affords the most likely prospect of bearing life.

Both nations have publicly accepted the challenge to carry out such exploration, and both view the endeavor in technological and political terms as well as in purely scientific terms.

A comparison of U.S. and Soviet efforts is useful because it can provide insight into the objectives and "style" of the participants and illuminate the intrinsic physical and technologcal restrictions and opportunities which are to be taken into account in any attempt to lift the veil of secrecy from the mysterious red planet. Finally, such a comparison provides a realistic basis for predicting the course of exploration of Mars in the coming decade. We feel that such a prediction on the basis of present efforts may be of particular current interest to the American scientific community because the widespread acclaim accorded Mariner IV is likely to be interpreted as implicit endorsement of the rest of the U.S. effort to explore Mars.

In this article we examine, first, the history of the U.S. effort to explore Mars, starting with 1960, when reasonably detailed plans were initially presented. Inasmuch as a considerable amount of information on planning and projected schedules is available, particularly from congressional authorization testimony, a detailed picture can be reconstructed of the study and project-definition phase of the U.S. effort, and of the hardware and flight-operations phase, which culminated in the success of Mariner IV.

This morphological picture of the U.S. program will be of particular aid when we consider the Soviet program. Virtually no direct information is available regarding the technology or proposed scheduling of future Soviet Mars probes. However, there is a considerable amount of technical information available about Mars I, Zond II, and Zond III, from which a consistent pattern emerges. Significant technological aspects of both programs are the capability for obtaining pictures and returning them to the earth and the ca-

Table 1. Summary of Mars exploration attempts by the United States and the U.S.S.R.

Name	Nation	Spacecraft weight (lb)	Mission	Launch	Spacecraft failure	Encounter	Remarks
Unnamed	U.S.S.R.	2,000 (est.)	Flyby?	10 Oct. 1960			Booster failure
Unnamed	U.S.S.R.	2,000 (est.)	Flyby?	14 Oct. 1960			Booster failure
Unnamed	U.S.S.R.	2,000 (est.)	Flyby	24 Oct. 1962			Failed to leave parking orbit
Mars I	U.S.S.R.	~2,000	Flyby	1 Nov. 1962	21 Mar. 1963		Failed after 61% of flight
Unnamed	U.S.S.R.	2,000 (est.)	Flyby	4 Nov. 1962			Failed to leave parking orbit
Mariner III	U.S.	~ 600	Flyby	5 Nov. 1964			Shroud failed in heliocentric orbit
Mariner IV	U.S.	~ 600	Flyby	28 Nov. 1964	None	14 July 1965	Successfully acquired planetary data
Zond II	U.S.S.R.	~2,000	Flyby	30 Nov. 1964	2 May 1965		Failed after 61% of flight
Zond III*	U.S.S.R.	~2,000	Lunar flyby and continued operation to Mars distance	18 July 1965	Still operating	Not applicable	Photographed reverse side of moon; carries infrared and ultraviolet spectrometers

* Test shot for future Mars probe.

Table 2. Summary of Venus exploration attempts by the United States and the U.S.S.R.

Name	Nation	Spacecraft weight (lb)	Mission	Launch	Spacecraft failure	Encounter	Remarks
Unnamed	U.S.S.R.	1,500 (est.)	Flyby?	4 Feb. 1961			Failed to leave parking orbit
Venik I	U.S.S.R.	~1,500	Flyby	12 Feb. 1961	27 Feb. 1961		Failed after 17% of flight
Mariner I	U.S.	~ 450	Flyby	22 July 1962			Booster failure
Unnamed	U.S.S.R.	1,500 (est.)	Flyby?	25 Aug. 1962			Failed to leave parking orbit
Mariner II	U.S.	~ 450	Flyby	26 Aug. 1962	None	18 Dec. 1962	Success
Unnamed	U.S.S.R.	1,500 (est.)	Flyby?	1 Sept. 1962			Failed to leave parking orbit
Unnamed	U.S.S.R.	1,500 (est.)	Flyby?	12 Sept. 1962			Failed to leave parking orbit
Zond I	U.S.S.R.	1,500 (est.)	Flyby?	2 Apr. 1964	Uncertain		
Venik II	U.S.S.R.	~2,000	Flyby?	12 Nov. 1965	Still operating		
Venik III	U.S.S.R.	2,000 (est.)	Flyby?	16 Nov. 1965	Still operating		
Unnamed	U.S.S.R.	2,000 (est.)	Flyby?	23 Nov. 1965			Blew up in orbit

pability for landing useful experiments. Photography is both a very important and a very difficult remote measurement, while the chemical and biological exploration of the Martian surface cannot even be attempted until direct investigation of the surficial materials has become practicable.

We end with specific conclusions, including a discussion of the possible results of U.S. and Soviet efforts in the next 5 to 10 years. It is our hope that a careful description of the two national efforts to explore Mars and the limited conclusions which follow from that description will contribute to the development of perspective as the United States makes new technological, economic, and scientific choices regarding the exploration of space over the coming decades.

United States Program

Five and a half years ago a leading NASA official presented to Congress a statement of goals of the U.S. lunar and planetary program over the half decade 1960–65 and of the basic principles guiding the effort (*2*).

> The NASA has established a sound program for the exploration of the Moon, Mars, and Venus which is designed to provide leadership in acquiring scientific knowledge about these bodies. The program is not an extravagant one. Rather, it is soberly conceived to exploit an orderly evolution of launching vehicles, spacecraft, and scientific payloads to the achievement of several selected goals. Within the next half decade these goals may be simply illustrated by their related missions, which are listed below with their dates of earliest achievement:
>
> 1960: Interplanetary probes.
>
> 1960: Lunar orbiters.
>
> 1961–62: Lunar impacts (reconnaissance).
>
> 1962: Planetary probes to Mars and Venus.
>
> 1963–64: Lunar soft landings.
>
> 1965: Planetary orbiters to Mars and Venus.
>
> 1965: Lunar soft landing with mobile vehicle.
>
> This mission schedule has been developed in accord with the following principles:
>
> 1. Select the most important goals and pursue them with determination.
>
> 2. Establish an evolutionary sequence of missions where each step paves the way for the more difficult phase to follow and which makes full use of increased technological capability as it becomes available.

This outline of a sustained evolutionary program of planetary exploration aimed at U.S. leadership in this field illustrates very clearly the original basis and intent of the U.S. program. Table 3 shows, in an approximate way, booster capability required for various Mars missions. Thus, the early U.S. plan called for the use of an Atlas-Centaur booster in 1962 (Table 3, category 2) and the use of a Saturn booster (category 3) in 1965.

Mariner C program. The evolutionary program envisioned by NASA had hardly been formulated when funding limitations precluded a Mars mission in 1962. This setback was followed by difficulties in the development of the Atlas-Centaur launch system, leading to a cancellation of the proposed 1962 flight to Venus of a 1200-pound spacecraft. In order to begin some kind of early planetary program, the Atlas-Agena launch vehicle was designated for a Venus mission in 1962. This improvisation was a particularly fortunate one for the U.S., because the Atlas-Centaur system was not to be ready for 1964 missions either. Thus, even before the successful launch of Mariner II toward Venus in August 1962, design studies were proceeding at the Jet Propulsion Laboratory for a flight to Mars in 1964; these studies were based on use of the Atlas-Agena system and as much of the Venus spacecraft hardware as possible. In November 1962, perhaps as a result of the launch and initial flight success of Mariner II, the go-ahead was given for the 1964 Atlas-Agena mission to Mars, to be termed Mariner C.

The Mariner C spacecraft to Mars necessarily was limited to about 575 pounds, less than half the weight of the Atlas-Centaur spacecraft originally planned for the U.S. program and less than a third the weight of Mars I, which had just been launched by the U.S.S.R. Indeed, there was considerable question whether Mariner C could carry out scientifically meaningful observations at the planet. The carrying of any kind of landing capsule was out of the question. Weight limitations even ruled out mechanization of the high-gain antenna so that it could be reoriented periodically for tracking the earth. Ingenious spacecraft design permitted utilization of a fixed high-gain antenna which could be used without reorientation of the spacecraft. This resulted in a simpler operational sequence than that used by the Soviet Mars I probe. The mission was severely limited in its photographic capability by the overall weight limitation and by the limited time available for development; the total amount of pictorial data that could be broadcast back to the earth was only a tiny fraction of the amount that might be considered adequate for viewing an unknown planetary surface. The 21 Mariner IV pictures contain, altogether, about as many picture elements as a single Ranger photograph contains, and only about 1 percent of the elements contained in an ordinary 9- by 9-inch (23- by 23-centimeter) aerial photograph (*3*). It was not possible to carry infrared or ultraviolet spectrometers.

On the other hand, the orientation system of the Mars spacecraft (which "locked onto" the sun and Canopus) was more sophisticated than that of the Venus spacecraft (which locked onto the sun and the earth), and the Mars spacecraft were designed to transmit many more data than the Venus spacecraft, over greater distances, and to operate unattended in a complete vacuum, internal and external, for more than twice as long.

On 5 November 1964, an Atlas-Agena rocket operated satisfactorily in an effort to place Mariner III on a Mars trajectory. However, a new, specially designed, lightweight shroud for protecting the spacecraft from aerodynamic heating collapsed during ascent, preventing the solar panels and other spacecraft components from unfolding properly. In a brilliant improvisation, within 3 weeks the nature of the failure had been diagnosed, the diagnosis had been confirmed by laboratory testing, and a new shroud had been designed, fabricated, tested, and installed. Thus, it was possible to fire the second Atlas-Agena during the 1964 launch opportunity. On 28 November 1964, Mariner IV was injected on a trajectory toward Mars. On 5 December, a mid-course trajectory correction was performed, causing the spacecraft, 7 months later, to pass 6188 miles (9900 kilometers) from the planet's surface.

On 14 July 1965, Mariner IV flew by the planet, obtained pictures of resolution up to 30 times the best resolution ever before achieved, determined that the magnetic dipole moment of the planet was less than 1/3000 that of the earth, determined that there were no radiation and dust belts, and discovered that the atmospheric pressure at the surface was significantly lower than had been indicated by terrestrial measurements (*4*). A brilliant technological improvisation had suddenly become a historic scientific achievement.

It is important also to note that, of

Table 3. Mars exploration launch vehicles and associated mission capabilities. Categories are in terms of total weight at Mars.

Possible launch vehicles	Possible missions	Earliest availability of launch vehicle
	Category 1: 500–600 pounds	
Atlas-Agena	a. Short-lived flyby	1961 (U.S.)
	Category 2: 1,000–2,500 pounds	
Atlas-Centaur	a. Extended-lifetime flyby with nonsurvivable capsule	1966 (U.S.) 1960 (U.S.S.R.)
Titan IIIC	b. Flyby and return	
Venik (U.S.S.R.)	c. Small orbiter	
	Category 3: 4,000–10,000 pounds	
Saturn I with second stage	a. Moderate orbiter with minimum-size lander	1968 (U.S.) ? (U.S.S.R.)
Titan IIIC with additional stage	b. Flyby and return with minimum-size lander	
"Proton" booster with additional stage (U.S.S.R.)	c. Extended-lifetime flyby with moderate-size lander	
	Category 4: 30,000–70,000 pounds	
Saturn V	a. Multiple large orbiters and landers	1971 (U.S.) ? (U.S.S.R.)
U.S.S.R. ?	b. Large orbiter plus very large lander	
	Category 5: 150,000–350,000 pounds	
Chemical plus nuclear	Manned landing and return	1980 ?

the two spacecraft readied for the Venus mission, only one, Mariner II, was successfully injected on a trajectory toward Venus. Of the two spacecraft readied for the Mars mission, only one, Mariner IV, was successfully injected on a trajectory toward Mars. The reliability of the Mariner spacecraft itself is indeed remarkable—two successes out of a sample of two. This feat is all the more impressive when compared to the Soviet record of three spacecraft failures out of three tries (two for Mars and one for Venus) (*5*), even though the Soviets had an advantage in payload weight (their payload maximum being more than three times the U.S. maximum) and an advantage in development and testing time of at least 2 years (see Tables 1 and 2).

It is thus hard to imagine how the Atlas-Agena Mariner program for Mars and Venus could have surpassed its actual performance, or how the same results could have been achieved with fewer launches or less costly spacecraft. Consquently it can be concluded that the present U.S. "lead" in planetary exploration has been brought about by unusually good engineering —and good luck—supported by a minimum of economic resources and launch vehicle capability.

The total prelaunch cost of the Mariner C program was about $84 million (*6*, p. 1819; *7*). The estimated cost of readying and flying the spare Mariner C spacecraft to Mars in 1967 was about $30 million; however, in August 1965 it was decided to terminate the Mariner Mars program (*8*, p. 354).

Atlas-Centaur program. What had originally been planned to be the mainstay of the U.S. planetary program, a 1200- to 1500-pound spacecraft launched by the Atlas-Centaur, was initially designated "Mariner B for Mars." The landing of a simple capsule had high priority in the Atlas-Centaur concept—the program name even evolved to "Mars/Venus Lander" after the Atlas-Agena system had to be substituted for the 1962 Venus and 1964 Mars launches. Because of budgetary limitations this program was not scheduled for the 1967 launch opportunity and, finally, early in 1965, plans for its use in 1969 also were dropped in favor of a larger system called Voyager (*9*). Late in 1965 it was decided to go ahead with the development of an economy-model, 800-pound "Mariner type" spacecraft to be launched by an Atlas-Centaur in 1969 (*10*), as it was becoming obvious that NASA resources would not allow for readying the large Voyager system until well into the 1970's.

It is estimated that the 1500-pound spacecraft would have been capable of acquiring 20 or more times the amount of picture data Mariner IV obtained, along with infrared and ultraviolet spectra. The greater information capability would have arisen from greater data-storage capacity, a larger steerable antenna (hence a higher rate of communicating data and a longer transmission time), a higher level of radiated power, and projected increases in antenna gain at the earth receiving stations. An articulated scan platform would have provided greater freedom in obtaining photographic and spectral data.

The landing-capsule concept for the projected Atlas-Centaur systems has been severely revised as the estimates for surface pressure of Mars have declined (as a result of new ground-based measurements and, finally, of the Mariner IV occulation) from about 10 percent to less than 1 percent of the value for the earth. For so low a pressure, the useful survivable scientific payload is very small; it is likely that the Atlas-Centaur system could have provided at best only a very limited lander capability. On the other hand, it is very well suited for an extended-lifetime flyby mission; it is capable of carrying a considerable amount of photographic and other remote-sensor instrumentation close by the planet and then returning the data, over the ensuing weeks and months. It has marginal capability for a return mission—that is, for returning to the vicinity of the earth—and thus for transmitting many more data over the vastly decreased transmission range. Such a return mission was attempted in 1959 (for the moon) by the U.S.S.R. with Lunik III, and proposed at that time (*11*) and again in 1965 (*3, 12*) for the U.S. Mars program.

With launch vehicle systems of only slightly greater capability, such as one based on the Titan IIIC or the Soviet Venik system, flyby and return missions become quite feasible. An orbiting mission of minimum capability is also possible, but is more difficult technically.

Voyager program. As was reflected in the 1960 testimony quoted earlier, it was recognized at the outset that the orbiting of large payloads around Mars and Venus, and the landing of significant payloads on the surface of Mars, would require substantially larger payload capability at Mars than the 1000- to 2500-pound spacecraft just discussed would have. Until very recently it has generally been thought that this requirement would be met by use of the Saturn IB booster combined with a second stage, followed at some (indefinite) later date by the Saturn V moon rocket; this general concept has been called the Voyager program since 1961. It remained strictly a study program until 1965, when a serious project-definition phase was initiated, involving the expenditure of $43 million in fiscal year 1966 (*13*, p. 459). The objective of this program was utilization of the Saturn IB booster with a Centaur upper stage to place a 7000- to 10,000-pound system, with both orbiting and landing payloads at Mars in 1971 and 1973 (*13*, p. 459). In addition, the basic hardware was to be adaptable, with minimum modification, to other missions, including missions to Venus; thus the program would lead to development of a widely useful spacecraft system of high capability (*13*, p. 459). Serious consideration was given to a possible test flight past Mars in 1969 (*13*, p. 528), which would help fill the gap created by the suspension of plans for an Atlas-Centaur mission in 1969.

By 1971 or 1973, the Saturn IB-Centaur combination would be capable of landing, from a Mars orbit, a sizable scientific payload, of perhaps more than 100 pounds, on the surface of Mars. With this or any of numerous other possible modes of operation, the category 3 capability (see Table 3) would have permitted extensive chemical, and at least preliminary biological, exploration of isolated parts of the Martian surface, and extensive remote mapping of the entire planet.

The total cost of the Saturn IB-Centaur Voyager program through 1973 was estimated at $1.3 billion, corresponding to an annual expenditure of nearly $200 million starting in fiscal year 1967 (*8*, p. 144; *14*).

October 1965 brought another major change in the proposed U.S. effort to explore Mars. The entire Saturn IB-Centaur concept for Voyager was abandoned, along with any test flight or other Mars mission in 1969 (*15*). Instead, it was decided to use a single Saturn V vehicle to launch two orbiter spacecraft toward the planet in 1971. The first landing attempt would not come before 1973. However, even this stretched Voyager timetable could not be supported in the coming fiscal year. On 23 December 1965, plans for any 1971 Voyager mission were dropped entirely. To fill the gap, the abbreviated 1969 Atlas-Centaur Mars program was initiated, and a single Mars Mariner C spacecraft, left over from the 1964 Atlas-Agena mission, will be slightly modified and flown to Venus in 1967.

The history of the U.S. program is summarized in Fig. 1, at left.

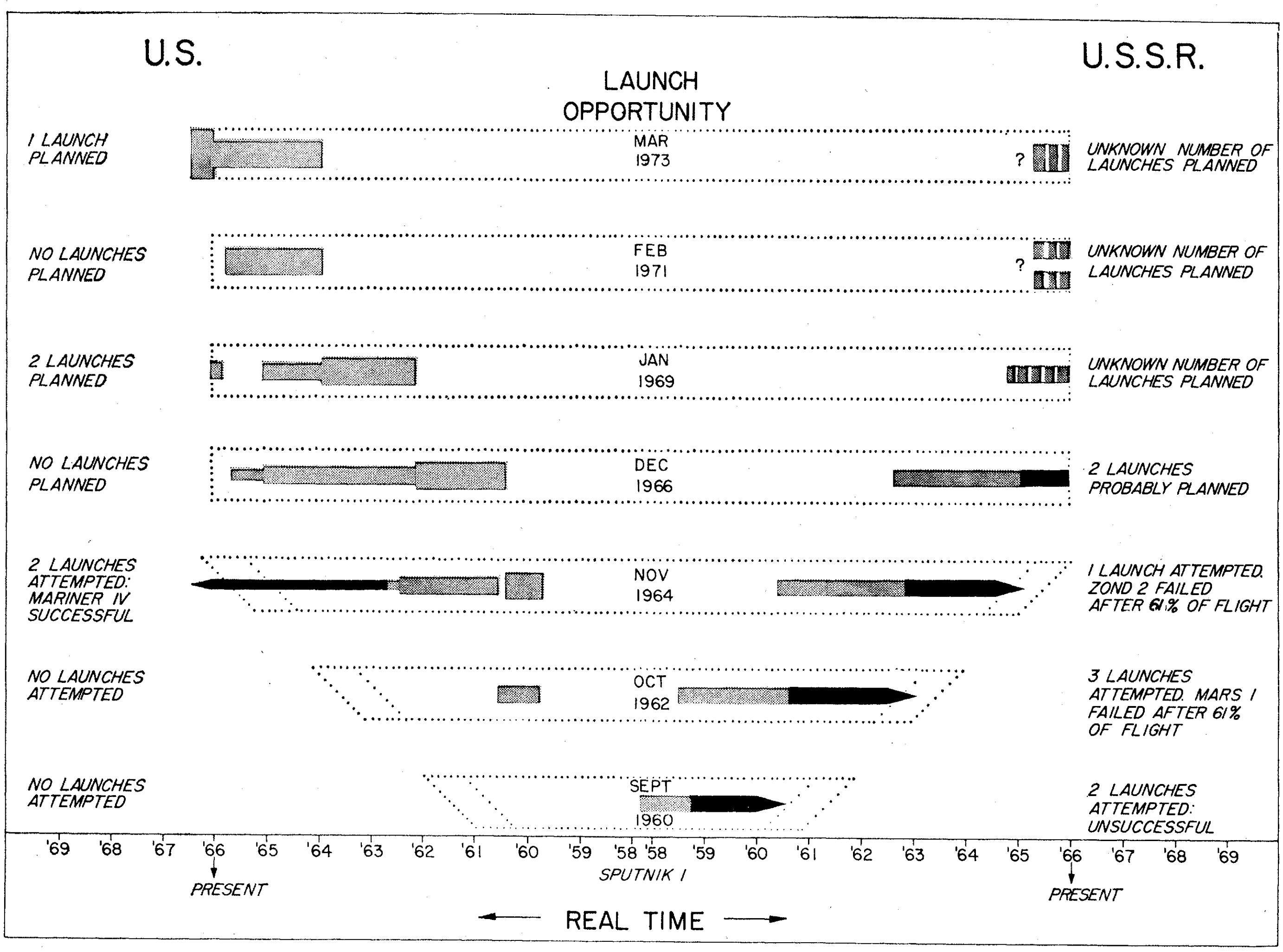

Fig. 1. Comparative data on U.S. and Soviet efforts to explore Mars. The U.S. and Soviet programs are shown back-to-back in bar-graph form, from the launching of Sputnik I in October 1957 to the present. In the U.S. program (at left) the horizontal time axis increases from the center toward the left, whereas the convention is reversed for the Soviet program (at right). The vertical axis (the same for both programs) is simply an ordering of the successive launch opportunities for Mars, which recur every 25 months. Each launch opportunity is enclosed by a dotted line; members of a pair of slanted dotted lines correspond to launch and encounter times, respectively. (Solid bar) Period during which actual flight hardware was being fabricated and tested prior to launch, and period of flight, where applicable. (Lighter shading) Study and project-definition phases. The dashed bars used for some future Soviet programs indicate conjecture. The four increasing widths of bars correspond, respectively, to programs aimed at placing 500–600 pounds, 1000–2500 pounds, 4000–10,000 pounds, and 30,000–70,000 pounds at Mars.

Soviet Program

The Soviet program for the exploration of Mars has continued without interruption since its inception in 1960, despite repeated mission failures. Because of the Soviet policy of releasing information only when a mission has been successful, little has been reported on the techniques and objectives of the program. Consequently, speculation must frequently be substituted for information. However, certain information, such as the reported number of missions attempted, is reliable; from this we can draw conclusions about the pace, efforts, objectives, and continuity of the exploration program. In many ways the Soviet performance reflects goals and approaches very similar to those stated by the U.S. in 1960.

History of the program. In all the Soviet planetary missions to date, apparently the same booster and the same launch technique have been used: three stages of a four-stage rocket place a heavy satellite in a parking orbit, and, at the proper time, the fourth stage is fired to place the spacecraft on its desired trajectory (*16*). This is a category-2 booster system, which can launch a 2000-pound spacecraft to Mars. This booster has somewhat greater capability than the Atlas-Centaur, which was selected to initiate the U.S. program.

The program began with the attempted launchings of Mars probes on 10 October and 14 October 1960 (*17*). At this time the large booster failed to put the heavy satellite in orbit, so these missions never got under way.

Three more vehicles were launched during the 1962 launch opportunity. Two of these, launched on 24 October and 4 November, failed to leave their parking orbits. However, the third was successfully placed on the desired trajectory on 1 November and became known as Mars I. Since the Soviets released a good deal of information about the Mars I probe, this mission can be discussed in some detail. (It is assumed that the 24 October and 4 November spacecraft were identical to the Mars I.)

The Mars I "automatic interplanetary station" consisted of two hermetically sealed compartments: an orbital compartment and a planetary compartment. The orbital compartment contained those instruments designed to operate during the flight to Mars, and the planetary compartment contained the equipment designed to operate in the vicinity of the planet (*18*). The compartments were maintained at a temperature between 15° and 20°C and at a pressure of 850 millimeters of mercury. The spacecraft was 3300 millimeters long, and the diameter of the orbital compartment was 1100 millimeters; the spacecraft measured 4000 millimeters across the solar battery panels and weighed 893.5 kilograms.

The vehicle carried many antennas, including a large parabolic antenna which resembled the 2-meter dish on Venik I. This antenna on the Venus probe remained folded during most of the flight and was expected to unfold when the station arrived in the vicinity of Venus (*19*). Presumably the Mars probe operated in a similar manner, with most of the antennas and the solar battery panels extending immediately after separation from the booster and the large dish unfolding after the vehicle reached Mars. This sequence may have been necessary in order for certain instruments, such as the camera, to have an unimpaired view of the surface. The large antenna and the solar panels were pointed in opposite directions, so, unlike the situation for Mariner IV, it would be necessary for the spacecraft to perform a maneuver before each transmission to earth. The probe's radio transmitters operated on frequencies of 183.6 and 922.76 (*20*) and about 3750 and 6000 (*21*) megacycles per second.

Mars I was launched on 1 November 1962 and was expected to reach Mars on 19 June 1963. The trajectory without mid-course correction would have taken it within 193,000 kilometers of the planet (*22*). A correction was planned to ensure that it passed within 1000 to 11,000 kilometers of the surface (*23*). However, it is not known whether this maneuver was executed. The last contact with the probe was made on 21 March 1963. Analysis of the telemetry received at that time revealed that a failure had occurred in the attitude control system which maintained the vehicle's inertial orientation (*24*). Consequently, the highly directional antenna was not aimed properly for its narrow beam to intercept the earth.

Analysis of the trajectory indicates that the spacecraft approached Mars with the hyperbolic velocity of 3.97 kilometers per second at an angle of 33 degrees with the Mars-Sun axis (*25*). This is the apparent velocity from the point of view of a Martian observer; it increases as the probe gets nearer the planet. The maximum velocity depends upon the altitude of closest approach. The trajectory flown corresponded to a minimum earth-departure energy—that is, the most economical energy, at launch, for a simple flyby mission. Although there were hints that the Mars I was to be an orbiter (*26*) or a flyby-and-return (*27*) mission, it is unlikely that the vehicle contained sufficient propellant to produce the increment in velocity required for orbiting or return. Probably the mission was simply an extended-lifetime flyby.

The next Soviet Mars probe, Zond II, was launched from a parking orbit on 30 November 1964. The first few radio contacts, on 1 December, indicated that the power level was about half that expected (*28*). Lack of a thorough understanding of this problem may have delayed the check-out of another vehicle, thus accounting for the Soviet failure to launch a second probe during the 1962 launch opportunity.

Very little was reported about the mission of Zond II or the scientific equipment aboard. However, the probe did contain a new plasma rocket-control system designed to keep the spacecraft properly oriented to the sun (*29*). This could be of particular significance, since malfunction of the Mars I control system was thought to be the cause of that probe's failure (*24*).

Zond II was expected to reach Mars on 6 August 1965 (*30*). Although no midcourse correction was ever announced, one probably was effected, since it was announced on 17 February that Zond II should pass within 1500 kilometers of the planet (*30*, p. 482). The spacecraft's communication system was operating irregularly during April, and by 5 May it had quit entirely. The cause was thought to be a failure in the solar-cell power system (*31*). Zond II transmitted on a frequency of 922.75 megacycles (*30*, p. 481).

The Zond II hyperbolic approach speed was 3.77 kilometers per second at an angle of 44 degrees with the Mars-Sun axis. The velocity at closest approach (1500 kilometers) was 5.62 kilometers per second (*32*). The trajectory chosen was not a minimum-energy one, but, significantly, it did minimize the hyperbolic approach velocity. This procedure would be desirable if the spacecraft were to orbit the planet (this would require a change in velocity of about 3.8 kilometers per second), or if a capsule for entering the atmosphere were to be ejected. A change in velocity of 3.7 kilometers per second (with orientation of the vehicle opposite to what it would be for orbiting) would have caused the probe to return from Mars to Earth in 220 days (*32*).

It appears obvious that Zond II was intended to do something more than merely fly by Mars. A step in difficulty beyond a simple flyby, and one often considered for projected U.S. missions of comparable capability, is the ejection of a small capsule (100 to 500 pounds) by the vehicle shortly before encounter with the planet. If the capsule is suitably aimed and designed, it will enter the atmosphere, be slowed by aerodynamic braking, and impact the surface very roughly, perhaps being destroyed. A suitably instrumented capsule of this type can transmit to the flyby vehicle very important information about the atmosphere during entry, and perhaps even certain information about the impact itself, making possible a determination of the bearing strength at the impact site. For a spacecraft to orbit the planet or to fly past it and return to earth in a reasonable time would require not only greater weight of retropropellant, storage tanks, and auxiliary equipment but also longer-lived and perhaps more complex equipment. Consequently, we think the Soviets may well have a nonsurvivable capsule system as part of their category-2 Mars spacecraft, but that they may not yet have designed that spacecraft to orbit Mars or to return to the earth. It is possible that such a capsule system is also part of the Venus flyby spacecraft; such a system might lead to important new understanding of the temperature distribution and composition of the atmosphere of Venus.

It is worth noting, in this regard, that even before Lunik III photographed the moon, Lunik II had impacted the lunar surface, carrying survivable metal medallions bearing Soviet insignia.

The Soviets have now had six consecutive failures in their efforts to explore Mars. The phototelevision system and other equipment designed to operate in the vicinity of Mars have never had an opportunity to perform. Consequently, on 18 July 1965, Zond III was launched to test the operation of these subsystems as well as the stabilization and communication system over long times and great distances. This vehicle may have been the second spacecraft scheduled for launch in November 1964, and not launched at that time because of power problems with Zond II. Zond III was placed on a trajectory which first took it within 10,000 kilometers of the moon, and on which it will continue into space until it reaches the empty orbit of Mars (*33*).

During the flyby, the spacecraft took pictures of the moon and transmitted these to earth from a distance of 2.2 million kilometers (*34*). Since that time, pictures have been sent to the earth from 12.5 million kilometers (*35*) and from 31.5 million kilometers (*36*) to test the performance of the readout system. These tests are to continue until radio communication is lost, and it is hoped by the Soviets that this distance will exceed the transmission distance required for a Mars mission. Wavelengths in the centimeter band are used to transmit the pictures (*37*), a fact which suggests that this is the same communication system which was designed for the Mars I. A midcourse correction was incorporated in the trajectory, to further simulate a Mars mission (*38*).

Photographic efforts and capability. The Soviets demonstrated an early appreciation of the value of pictures to an exploration program with the launching and successful mission of Lunik III in October 1959. The unnamed Mars probes, launched just 1 year later, may have contained photographic equipment very similar to that used in Lunik III but adapted to the longer mission. Mars I, launched about 3 years after Lunik III, contained photographic equipment intended to take pictures of Mars and transmit them back to earth. The pictures were to be taken through different light filters and from different points along the trajectory, so that the planet would not always appear as a circular disk (fully lighted), as it does from the earth (*39*). Moreover, in these pictures the Martian moons, Phobos and Deimos, which appear as points when viewed with a telescope, were to be resolved (*39*). If photography is started when the spacecraft is at some distance from Mars, the pictures will show Phobos and Deimos and will also show most of the surface of Mars as it rotates on its axis, once every 24.6 hours.

About 2 years later Zond II was launched. Although it was never stated that Zond II contained photographic equipment, presumably it did, inasmuch as Zond III took pictures of the moon to test equipment designed for future use on a Mars mission. Moreover, the basic system of taking pictures and transmitting them from the spacecraft to the earth was the same for Lunik III and Zond III. Therefore, it is interesting to compare the pictures and see the improvement in the performance of this equipment after 4½ years, and to become somewhat familiar with what appears to be a "standard" Soviet photographic payload.

Tables 4 and 5 summarize the performance of both U.S. and Soviet photographic systems which have been used for lunar and Martian exploration. Data for the U.S. Lunar Orbiter, which is scheduled to fly in 1966, are also included for comparison. Of course it is not possible to make meaningful judgments as to preferred systems without considering the objectives of the mission. However, in exploring unknown land surfaces, it is frequently not possible to tell, in advance, where or at what resolution the most important information will be obtained.

Table 4. Comparison of photographic systems.

Lens	Photographic interval	Photographic distance (km)	Approximate resolution on Mars or Moon
	Lunik III (4 Oct. 1959)		
200 mm, *f*/5.6	40 minutes	65,200	40 km
500 mm, *f*/9.5		to 68,400	16 km
	Ranger VII (28 July 1964)		
25 mm, *f*/1.0 (three);	17 minutes	1,800	2.2 km
75 mm, *f*/2.0 (three)		to 0.48	to 0.5 m
	Mariner IV (14 July 1964)		
300 mm, *f*/8	25 minutes	16,800 to 9,900	3 km
	Zond III (18 July 1965)		
106.4 mm, *f*/8	25 minutes	11,600 to 10,000	5 km
	Lunar Orbiter (under development)		
75 mm	1 month	46 (minimum)	8 m
600 mm			1 m

Moreover, ground resolution alone is not a fair criterion, since, by changing the focal length, it is usually possible to trade area coverage for resolution. Probably the single most meaningful way to denote the usefulness of a photographic probe is to indicate the total amount of information returned (*3*) from a given distance. For this reason, Mars missions should not be compared directly with lunar ones. It will be important to see whether the Zond III does transmit its 10^8 bits over the required range—an objective of the Mariner B mission. This would represent about a 20-fold increase in total amount of data returned over the total for Mariner IV.

Scientific objectives. The overall scientific goals for the Soviet exploration of Mars have not been stated explicitly. However, considerable scientific research on the planet by individuals working in such specialized organizations as the "Astrobiological Institute" is evidenced in the professional literature. In addition, there are certainly some reputable Soviet scientists with intense interest in, and concern for, extraterrestrial biology. Accordingly, it can be concluded that the overall scientific objectives of the U.S.S.R. in exploring Mars probably do not differ significantly from those of United States: General scientific exploration, with particular attention to the possibility of life.

The scientific payload of the Soviet flyby spacecraft, Mars I, was described as follows (*21*).

> The following scientific apparatus is on board the station to carry out scientific investigations: a phototelevision unit to photograph the surface of the planet Mars; a spectro-reflectometer to detect organic coverings on the surface of the planet; a spectrograph to study the ozone absorption band in the atmosphere of Mars; a magnetometer to detect the magnetic field of Mars and to measure the magnetic fields in cosmic space; gas discharge and scintillation counters to discover radiation belts of Mars and to study cosmic radiation spectrum; a radio telescope to study cosmic radio emission in the 150 and 1500 m wavebands; special pick-offs (traps) to record streams of low-energy protons and electrons as well as the positive ion concentration near the planet Mars and in cosmic space; pick-offs to record micro-meteorites.

If we identify a "spectro-reflectometer" as a spectrometer designed to observe the reflected solar radiation in the near-infrared region, and "a spectrograph to study the ozone band in the atmosphere of Mars" as an ultraviolet spectrometer designed to observe the scattered sunlight from the atmosphere, then the Mars I payload corresponds closely to the Zond III payload (*40*). It also includes almost all the observations considered for the U.S. Mariner B-type flyby of the 1966 variety. A significant exception is an infrared radiometer for detection, hopefully, of night-time temperature anomalies on Mars. The experiment to study cosmic radio noise has not, to our knowledge, been seriously considered for any U.S. planetary probes.

The Zond III test flight included lunar tests of the infrared and ultraviolet spectrometers as well as the photographic system. According to the Soviet description of the result (*40*), there may be an anomalous reflection feature at 2600 angstroms; such anomalies can characterize distinct silicate mineral phases. If the presence of this feature is confirmed, then the Mars test flight will have resulted in an important, if not totally unexpected, discovery about the moon.

We have been unable to find any description of proposed Soviet scientific experiments for either simple or elaborate landers. We interpret this as a result of their general policy of secrecy regarding future plans rather than lack of interest.

The history of the Soviet program is summarized graphically in Fig. 1.

Table 5. Comparison of information returned.

Number of scan lines per picture	Approximate number of gray levels	Information per picture (bits)	Number of useful pictures	Transmission distance (km)	Total useful information per mission (bits)	Total information normalized to Mars distance (bits)
			Lunik III			
1,000	8	1.2×10^6	15	4.7×10^5	1.8×10^7	8.2×10^1
			Ranger VII			
1,150	64	7.9×10^6	400	3.8×10^5	3.4×10^9	1.0×10^4
300	64	5.4×10^4	3,900			
			Mariner IV			
200	64	2.4×10^5	21	2.2×10^8	5.1×10^6	5.1×10^6
			Zond III			
1,100	32	4.7×10^6	25	2.2×10^6	1.2×10^8	1.2×10^4
				1.3×10^7		4.2×10^5
				3.2×10^7		2.5×10^6
			Lunar Orbiter			
5,800	64	2.9×10^9	140	3.8×10^5	4.1×10^{11}	1.2×10^6

Conclusions

Comparison of past efforts. The Soviets embarked on a serious planetary exploration program shortly after their Sputnik I initiated the space age, in October 1957; the American effort was initiated about 2 years later. Both nations planned 1000 to 2000-pound flybys as the initial phase, with perhaps the capability to eject a small capsule. Both programs were aimed at returning on the order of 10^8 bits of close-up pictorial data, along with infrared spectra for detection of surface organic compounds and ultraviolet spectra for analysis of minor, but significant, atmospheric constituents, such as oxygen.

Soviet launch attempts toward Mars began in October 1960. In all, the Soviets have attempted at least six launches toward Mars and nine toward Venus, and one Mars test flight—a total of 16, and an average of three per year. On the basis of cost estimates for the Atlas-Centaur System, it is probable that a U.S. program comparable to the Soviet one would cost at least $125 million a year exclusive of costs of vehicles and launch. Thus the figure for total prelaunch costs of the Soviet flight program to date is perhaps at least $750 million. Indirect costs for a proportionate share of launch-vehicle procurement and development, tracking and launches, future mission studies, facilities, and so on, are probably at least comparable to direct costs, in both the Soviet and U.S. programs.

The United States was unable to attempt a 1962 launch toward Mars, as had been planned in 1960, due to development difficulties with the Atlas-Centaur launch vehicle, as well as to economic limitations. Continued technical difficulties with that launch vehicle also precluded its use at the next launch opportunity, in 1964. An improved program to use the Atlas-Agena launch vehicle permitted two launch attempts with a minimum-payload spacecraft toward Venus in 1962 and two toward Mars in 1964. The United States, therefore, has made four launch attempts toward Mars and Venus with a minimum system. Total prelaunch expenditures for the Atlas-Agena program were about $114 million. Thus the Soviets have spent between five and ten times as much on flight programs for planetary exploration as the United States has. Both countries so far have given about equal priority to Mars and Venus.

Comparative technological achievements. Of the first 11 Soviet planetary launch attempts, only two successfully placed spacecraft on planetary trajectories. Four out of five of the most recent attempts have been successful. The Soviets evidently have finally developed a highly reliable category-2 launch system for planetary missions. The Atlas-Agena launch system performed properly in three out of four attempts, if the failure of the special shroud for Mariner III is not counted against the basic launch system.

Of the six Soviet spacecraft injected into planetary trajectories, three failed during flight and three are currently operating satisfactorily. Regardless of whether or not the latter three carry out all their objectives, the fact that the Soviets have now accumulated a very large amount of engineering experience with a single category of spacecraft system would seem to indicate that reliable spacecraft of this type will be available for the 1967 and subsequent Mars opportunities. It is still possible, however, that some fundamental defect —for instance, penetrability by micrometeorites, with consequent pressurization failures—remains in the basic spacecraft system and will further plague their efforts. The U.S. was able to develop a reliable category-1 spacecraft without in-flight failures—a remarkable engineering feat which temporarily overcame the enormous Soviet advantage in starting time and level of expenditure. The long-term significance of the success of the Mariner technology will depend, however, on how much of that technology is utilized directly in future U.S. planetary missions.

Comparative scientific objectives and achievements. In objectives and approaches, the U.S. and Soviet programs so far have not differed significantly. The U.S. achieved the first few of these objectives because of the technological success of its Mariner IV spacecraft; the great scientific importance of those first results should be taken as an indication of the probable importance of succeeding observations from probes with greater capacity for gathering data and transmitting them to earth. As long as the objectives and approaches are similar, the respective scientific achievements of the two programs will continue to be determined solely by technological achievement.

Future prospects for the Soviet programs. The continued effort of the Soviets to develop a reliable 2000-pound spacecraft for a Mars flyby, culminating in the Zond III test flight, makes it likely that at least one, and probably two, such spacecraft will be launched toward Mars in December 1966. It will be surprising to us if at least one Zond spacecraft does not reach the planet and return new facts about it. Analysis of previous Soviet lunar photography suggests that the 1967 Mars probes may well attempt coverage of most of the planet at ground resolution of 5 kilometers or so, and perhaps, by the use of filters, in color. In addition, higher-resolution coverage may be obtained over a small area, near the time of encounter. Infrared spectra will also be acquired, in an effort to detect evidences of organic materials. The ultraviolet spectra to be acquired presumably will be similar to, but more extensive than, those acquired by a U.S. high-altitude rocket in 1965 (*41*); the long atmospheric path lengths obtained by viewing the limb from a flyby spacecraft may increase the sensitivity of the measurement. Analysis of the ultraviolet scattering observed by a flyby experiment, often also considered by the U.S., might increase understanding of the peculiar "blue clearing" and "blue haze" of Mars. Whether an infrared radiometer also will be flown, to look for volcanic heat sources on the nighttime surface of the planet, is an open question. Adequate payload weight apparently is available, but there has been no mention of such an experiment on Mars I or Zond III.

It would seem reasonable for the Soviets to continue flyby and simple capsule missions for the 1969 and probably even the 1971 launch opportunities. Such a procedure would permit close-up mapping of some seasonal variations in surface features as Mars moves through 4 to 6 years of its 15-year cycle of local season versus date of opposition of Mars and the earth. Also, it would provide an opportunity to change the parameters of various experiments—even to add experiments—in response to newly obtained data. In fact, a properly executed program of 2000-pound flyby missions might be expected to accomplish nearly all the objectives usually considered for orbiter missions requiring a category-3 booster.

There is no direct indication at present of Soviet intentions regarding the use of a larger, category-3, launch vehicle, particularly for landing a survivable payload on the Martian surface. On the other hand, the Soviet "Proton" satellite, weighing about 27,000 pounds, was boosted into earth orbit on 16 July 1965. The launch vehicle used in that endeavor, in combination with a suitable upper stage (which may or may not already be developed), should be capable of placing a system weighing 10,000 pounds or more at Mars. Planning on such a booster capability, the Soviets could conceivably begin now to develop a Mars lander spacecraft for use by 1969; however, 1971 seems to us the earliest likely date. This booster would also find application in the manned and lunar programs, which may well have higher priority than the interplanetary program. Also, it would be wise to delay the development of a category-3 spacecraft until the smaller and simpler systems have demonstrated their ability to operate for the required time and at full range.

One final aspect of the Soviet effort is significant, as compared with the U.S. effort: there evidently has been no slackening of the Soviet efforts to learn more about Venus—at this time Venik II and Venik III are proceeding toward that planet. If these or subsequent probes were to discover organic compounds in the Venusian atmosphere, or to determine that the actual surface temperature lies within a range that is of biological interest instead of in the excessively high range currently indicated by radio-emission observations, the relative scientific importance of the exploration of Venus and Mars could change overnight. It is indeed a measure of our ignorance of these bodies that merely a plausible nonthermal explanation of the high radio brightness of Venus could cause such a complete reappraisal.

In summary, the Soviets have expended far greater resources on planetary exploration than the United States has. They have developed, and continue to utilize, an independent launch capability for planetary exploration; they are able to modify their approach to the exploration of Mars as new data become available; they continue to direct substantial efforts toward the exploration of Venus as well, maintaining, thereby, considerable freedom of choice concerning future missions while gathering more data upon which to base future decisions.

Future prospects for the U.S. program. During 1965 the U.S. abandoned the concept of a step-by-step evolutionary approach to planetary exploration and attempted to substitute the goal of a major technological accomplishment—the direct search for life on Mars. It was hoped that a large-scale program could be maintained around this planning objective, and the Saturn IB-Centaur Voyager program was intended to be of this type.

This program would still have permitted an evolutionary approach had it been initiated early and aggressively enough; however, the switch in October 1965 to the Saturn V booster, at a cost of further delays, eliminated this alternative. Whatever may have been the justifications of expediency and experience that led to such an approach to national planning, it is clear that the resulting program would constitute a very large but not necessarily efficient utilization of funds for planetary exploration. Efficient and effective scientific exploration requires frequent reaction and readjustment to the new environment and the physical processes encountered, in terms of the scientific questions asked and the experimental tools utilized.

In this context, the improvised Venus (1967) and Mars (1969) missions have emerged as the projected U.S. effort to precede an eventual Saturn V Mars mission. Significantly, both the total estimated cost and the time scale are about the same as those of the Mariner improvisation begun in late 1961. The U.S. has again chosen to provide a minimum of resources in support of extraordinarily difficult technical undertakings; improvisation—and luck—will again be required if we are to learn new secrets from our nearest planetary neighbors.

The character of the U.S. program beyond 1969 is most difficult to project. Neither the evolutionary concept nor the costly single-step-to-Saturn V approach has been supported financially so far. Thus, by the end of 1967, the U.S. will again be faced with a fundamental choice in planetary exploration—whether to take another modest step in the exploration of Mars in 1971, perhaps exploiting the 1969 technology to permit landing of a simple survivable capsule, or to initiate a much larger and more costly Saturn V program, to begin in 1973 or 1975.

Perhaps by 1967 the U.S. will be ready to make an enduring national commitment to the exploration of the planets, and be ready to demonstrate intellectual appreciation of discovery as well as enthusiasm for technological achievement.

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