11 June 1976, Volume 192, Number 4244 SCIENCE

Détente in Space

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The space programs of the United States and Soviet Union have been bound together for nearly two decades through rivalry, competition, and, most recently, cooperation. The scientific consequences of these space activities have been to revolutionize the study of the solar system, to open the high-energy (x-ray, gamma ray, and cosmic ray) window to astrophysical observation, and to significantly influence the study of Earth itself, especially its atmosphere. Nevertheless, scientific research in itself never has been the principal justification for space expenditures. Even the sharply trimmed National Aeronautics and Space Administration (NASA) budget of the middle 1970's is still five times that of the National Science Foundation and twice that of the National Institutes of Health. Obviously, other factors, such as (i) popular appeal of space adventure and exploration, (ii) enhancement of national esteem and international prestige, (iii) utilitarian value, and (iv) stimulation of technological advance, form much of the basis of public and U.S. governmental support of "space." It is that pluralistic association of diverse attitudes and objectives which, when skillfully related to imaginative space missions, creates the opportunity for unique scientific achievement.

Thus, high ambition for science in space demands intellectual appreciation of the broader human activity, including relations between the United States and the Soviet Union, in which this ambition is embedded. Détente remains a controversial foreign policy within both nations; recently, it has even become an element in U.S. election-year debate. Nevertheless, continued growth of economic ties as indicated by the 1975 grain agreements would seem to show that the process of growing together is proceeding despite lingering distrust. In terms of scientific activity, if détente really can lead to enhanced communications between U.S. and Soviet scientists, the traditionally international character of scientific research will be fostered.

Now that the well-publicized Apollo-Soyuz mission has been completed, it is an appropriate time to review U.S. and Soviet interrelationships with regard to space, to identify the major space issues facing each country, and to focus on areas of possible common interest.

Manned Flight—Main Theme of the 1960's

Current space efforts are rooted in the development of ICBM (intercontinental ballistic missile) boosters in the late 1950's and in the related weapons race. Space efforts in both countries were cast from the beginning in the form of nationalistic rivalry between the two superpowers. The Soviet Union accomplished a number of impressive technical feats in space, including the launch of the first artificial Earth satellite (1957), the return of pictures from the far side of the moon by Luna 3 (1959), and the first manned space flight (1961). The United States was not prepared for the high level of public awareness of space activity that resulted, and early U.S. efforts included well-publicized launch vehicle failures.

In 1961 the United States made a major commitment in space. The moon landing (Apollo) program was chosen as a response that could overcome the initial U.S. lag through development of all-new Apollo hardware. This judgment correctly presumed that the U.S. industrial system would be better able to adjust to such a massive escalation of the space competition than would the Soviet industrial system. It also channeled much of the public concern about U.S. space capability into a positive, highly visible program with a fixed time scale and a clear criterion for success (*1*).

Space activities of the 1960's, therefore, were dominated by competition between the United States and the Soviet Union in manned space flight. Both nations started out with the roughly parallel Mercury and Vostok series, which were succeeded by the roughly parallel Gemini and Voskhod series. Both countries developed, almost simultaneously, the basic skills necessary for orbital manned space activities. However, during the middle 1960's, significant changes in patterns of development appeared. The Soviet Union began to experience difficulties both in new booster development and with spacecraft reliability. In contrast, by 1968 the United States had man-rated and flown four independent launch vehicles of consecutively larger size—the Atlas, Titan II, Saturn IB, and Saturn V (*2, 3*). The Soviet Union continues to this day to use for manned flight a modification of the launch vehicle used for the initial flight of Yuri Gagarin (*4*). Furthermore, the Soviet program experienced a series of in-flight spacecraft accidents, including the death of cosmonaut Komarov during the landing phase of an early Soyuz test flight and the deaths by anoxia of three cosmonauts in a Soyuz spacecraft returning from the Salyut space station (*2*). This performance decline was attributed to the death of the original chief designer for space, Sergei Korolev, who was regarded in the Soviet Union as a managerial genius (*5*). A realistic explanation may be a basic Soviet industrial weakness in the area of managing and developing complex systems that require the integration of enormous numbers of individual components and subsystems that are generated from

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many different sectors of the economy. Such industrial deficiencies may have been aggravated by haste stemming from highly competitive pressure to achieve space "firsts."

During the 1960's the Soviet Union had under development two significant lunar missions originally intended to precede the publicly stated U.S. target of 1969 for landing a man on the moon. The Zond 4 (1968), 5 (1968), 6 (1968), 7 (1969), and 8 (1970) flights were unmanned tests of a spacecraft being developed for manned flyby-and-return lunar missions. These test flights used the large Proton launch vehicle, and failure to man-rate it resulted in a decision to phase out the Zond series in 1970, some time after the successful lunar orbiting flight of Borman, Lovell, and Anders in Apollo 8 (1968). In addition, the early Proton failures delayed until after the initial U.S. manned landing a highly successful Soviet program of advanced unmanned lunar flights, including automated sample return and roving vehicles (*6*). Thus the inability to develop the Proton on schedule prevented a significant Soviet participation in the worldwide excitement stimulated by the U.S. Apollo achievements.

Over the years, there have been hints that the Soviet Union was developing a very large launch vehicle—much larger than the Proton and, in fact, larger than the Saturn V. There are reports of three launch failures of this huge launch vehicle (*7*). Certainly there were many public indications that the Soviet Union was once working toward a manned lunar landing with an eventual goal of a manned planetary mission (*8*). Whether or not the launch vehicle and spacecraft developments necessary for manned lunar activities are now being pursued seriously in the Soviet Union is difficult to assess.

The first Soviet space station is the Salyut, which weighs about 18,500 kg and is launched unmanned by the Proton launch vehicle; conventional Soyuz spacecraft and launch vehicles are required for ferrying men to and from Salyut. The death of the three cosmonauts returning to Earth aboard Soyuz 11 from Salyut 1 (1971) and the flight failure of the unmanned test Cosmos 557 delayed successful qualification of the Salyut system until after the introduction of the very successful U.S. Skylab mission. Skylab, which, for the most part, uses leftover Apollo hardware, weighs 75,000 kg and was visited in 1973 and 1974 by three successive crews who spent a total of 171 days in orbit.

However, Skylab, like Apollo, was a very large single endeavor, not an element in an evolutionary program. In contrast, the Salyut program is a continuing one; so far, two crews have spent more than 90 days in orbit in Salyut 4 and unmanned rendezvous has been successfully tested (*9*). It represents a major component of the evolutionary Soviet space plan (*8*). The very successful completion of Skylab, and especially of Apollo, removed for many U.S. citizens the primary justification of manned space flights. To these citizens, the space race had been won through the efforts of adventuresome U.S. astronauts; more of the same is not very exciting (Fig. 1). Broad domestic support for and acceptance of manned space flight is less evident than in the 1960's. In addition, the cost-effectiveness of man in Earth orbit was not adequately demonstrated to the military; it remains, at most, an issue in civilian space activities.

Instead, the emphasis of the U.S. civilian space effort is now on the development of cheaper and more versatile means of transporting payloads to and from Earth orbit. The space shuttle transportation system under development is a major new technological endeavor but involves little actual manned space flight for some time to come (*10*). Hence, in some ways, it can be regarded as a substitution for, rather than a continuation of, the U.S. manned flight program.

The Soviet Union must be facing a frustrating choice regarding manned space flight. Despite heavy investment for many years, Soviet performance has fallen further behind that of the United States. The Soviets are faced with continued investment requirements and, possibly, major revisions in industrial practice in order to catch up to the technological level of past U.S. space achievements. For the short term, the Soviet Union can pursue various manned space station operations in orbit while wondering whether, and how, the U.S. shuttle development will lead to renewed manned flight competition in the 1980's.

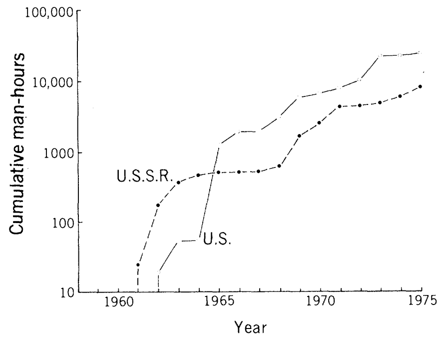
Extraterrestrial Exploration with Robots

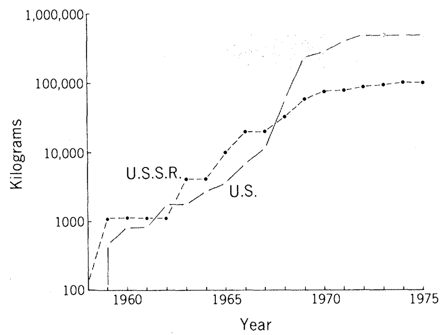
The very first use of Earth satellites by both countries was to explore the physical environment of Earth orbit with automated spacecraft. More than 40 Explorer satellite missions have been flown by the United States in a continuing program to study the particles and fields encountered in Earth orbit as well as to make many other measurements. The Soviet Union probably has carried out an even larger program, at least in terms of number of launches and, on occasion, the use of very heavy payloads.

In the early 1960's, lunar exploration was started by both the United States and the Soviet Union with automated vehicles. The Soviet Union emphasized symbolic results, such as the delivery of medallions to the surface of the moon. The U.S. pursued scientific return and the development of advanced unmanned technology to a greater extent (*11*).

In the later part of the decade, the Soviet Union deployed much more complex and versatile systems that were made possible by the Proton's capability to place about 6000 kg on a lunar trajectory and nearly 4000 kg in lunar orbit (*12*). Valuable scientific results were obtained by the Luna 16 and 20 sample returns and the Lunokhod (Luna 17 and 21) unmanned roving vehicles; although less spectacular, the Luna 19 and 22 orbiters may also have returned useful data. Press interviews by leading Soviet officials have described even more advanced plans for future automated lunar systems, including the coordinated use of Lunokhod to acquire samples and transport them to an automated sample-return vehicle for return to Earth, and plans for surface operations on the far side of the moon (*13*). Although there have been no lunar flights for more than a year, the Soviet Union had been launching automated spacecraft to the moon at a rate of about one per year (*2*). A comparison of the cumulative mass launched to the moon by each country is shown in Fig. 2. The United States has no active lunar flight missions at present; the only contemplated mission is a low-budget Lunar Polar Orbiter still to be proposed by NASA for authorization. However, the United States needs the means for renewed deployment of scientific instrumentation on the moon in order to build appropriately on the enormous scientific harvest associated with Apollo and on the unique and broad expertise of U.S. lunar scientists.

At Mars, the United States achieved great scientific success from modest investment with the Mariner 4 flyby (1965), the Mariner 6 and 7 flybys (1969), and the Mariner 9 orbiter (1971–72). The notion of an Earth-like Mars gave way to that of a moon-like one as a result of the first, limited observations; later the planet's surface was generally recognized to be dominated by extraordinary volcanic, depositional, and erosional features. Highly ingenious use of ground-based





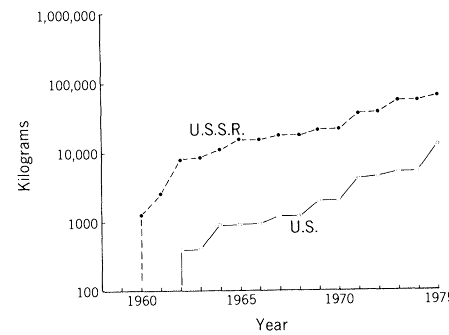


Fig. 1 (left). Cumulative man-hours in space. [Data from Sheldon (*2*)] Fig. 2 (middle). Cumulative mass of spacecraft launched to moon. [Data from Sheldon (*2*)] Fig. 3 (right). Cumulative mass of spacecraft launched to the planets. [Data from Sheldon (*2*)]

radar and aggressive supporting studies have enhanced the value of U.S. flight experiments. These efforts to explore Mars will reach a peak with the arrival at Mars in 1976 of the two Viking spacecraft now in flight. Each is intended to release from orbit a soft-lander equipped with by far the most complex suite of automated instruments ever flown in space.

In contrast to American successes and to their own efforts at Venus, the Soviet exploration of Mars has traveled a troubled road, despite at least 13 launch attempts over 15 years (*2; 14*, chap. 4). Communication with Mars 1 (1962) and Zond 2 (1964) was lost before either spacecraft reached Mars. No further Mars attempts were acknowledged until 1971 when the Proton booster was used to launch the first members of a new class of planetary spacecraft, Mars 2 and 3, which carried landers as well as retrosystems to achieve orbits. These spacecraft were similar in concept to Viking but carried less advanced scientific instruments. Mars 2 went into orbit but its capsule crash-landed. Mars 3 barely achieved a loose orbit and its lander transmitted unusable data for only 20 seconds.

The higher energy requirements for the Mars opportunity of 1973 precluded use of the new type of spacecraft for both orbiting and delivery of a soft-lander. Accordingly, the Soviets launched four of the new heavy spacecraft to achieve the original objective of two orbiters and two landers. Mars 4 and 5 (1973) were designed to go into orbit while Mars 6 and 7 (1973) carried soft-landers. But success still was not achieved. The retro failed to fire on Mars 4, so it passed uselessly by the planet. Mars 5 did achieve orbit and obtained new data, some of which were similar to that acquired by Mariner 9. The lander on Mars 6 returned limited temperature, pressure, and compositional data about the atmosphere but failed before landing on the surface, and the lander on Mars 7 failed to hit the planet (*15*). The scientific return from Soviet Mars flights has been quite small, especially considering the size and expense of the efforts. There was no renewal of Soviet efforts during the 1975 Mars launch window.

The Soviet experience in the case of Mars is similar, on a smaller scale, to their manned spacecraft history—inability to achieve adequate reliability with complex spacecraft operations.

The United States must decide whether, and how, to continue a first-rate exploration effort after Viking, within a much more restricted budget. Thus the U.S. position regarding future Mars efforts is similar to the dilemma in lunar exploration that was encountered after Apollo. After highly successful missions and wide recognition of efforts to explore both bodies, the United States has little follow-on program to exploit and continue that role in the future.

The Soviets launched during almost every Venus opportunity from 1960 to 1974 and eventually achieved success with the Venera 4 through 8 series of atmospheric probes. As a result, they evolved a reliable spacecraft, a dependable entry technology, and a capsule designed to survive briefly on the surface of Venus, where the temperature is close to 500°C and the pressure is 90 to 100 atmospheres. The instrumentation was gradually improved so that important scientific results were achieved by each successive mission.

In 1975, the flights of Venera 9 and 10 used the new heavy spacecraft launched by Proton that had previously been sent only to Mars. Venera 9 and 10 weighed about 5000 kg each, with perhaps nearly one-third of the weight devoted to capsules that were delivered into the Venus atmosphere. Each capsule transmitted, for about 1 hour, scientific data, including pictures from the surface of the planet. The parent spacecraft went into orbit, relayed the data from the capsule to Earth, and continued to make scientific measurements from orbit (*16*).

The United States, by comparison, has given Venus relatively low priority and has flown only remote-sensing missions [Mariner 2 (1962), 5 (1967), and 10 (1974)]. The long-delayed first U.S. attempt to place a modest payload (four probes, totaling 500 kg) directly into the atmosphere of Venus is planned to take place in 1978; even so, it was very nearly cancelled in Congress in 1975 (*17*). The relative payload weights and the degree of national support can hardly be encouraging to U.S. scientists anxious to study Venus. Thus far, the effectiveness of U.S. ground-based radar and optical studies, as well as Mariner radio occultation experiments and close-up ultraviolet pictures, have helped make possible the unique contributions by U.S. scientists to the study of Venus.

The Soviet Union, with its very large spacecraft capability at Venus, can now consider even more ambitious missions, such as long-lived "submersibles," balloons (*18*), or highly instrumented orbiters. In contrast, U.S. Venus missions will probably remain constrained by budgetary considerations. Small but capable atmospheric probes and, especially, radar mapping from orbit may offer the most cost-effective opportunities for unilateral scientific achievement under the circumstances (*19*).

In contrast to the Soviet Union's preoccupation with Earth's nearest planetary neighbors, the United States targeted Mariner 10 to utilize a close passage at Venus in 1974 to perturb its trajectory into a flyby encounter with Mercury, where an Earth-like magnetic field as well as a moon-like surface history were discovered. United States technology in space communications, navigation, and adaptive design for a harsh space environment resulted also in the first flyby of Jupiter, made by the modest U.S. probe Pioneer 10 (1973). New details of Jupiter's atmosphere and its interaction with the solar wind were revealed. Pioneer 10 will become the first manmade object to escape the solar system. Its sister spacecraft, Pioneer 11, is on a trajectory to encounter Saturn after carrying out a polar flyby of Jupiter in 1974. In addition, two new U.S. Mariner spacecraft with greatly augmented scientific instrumentation are being developed for launch in 1977 to observe Jupiter and Saturn and their satellites. Figure 3 shows the cumulative mass of spacecraft launched to the planets by the two countries. Obviously, the Soviet Union has expended a much larger effort than the United States.

The Soviet situation regarding exploration of the outer solar system may be analogous to that of the United States regarding Venus. Should the Soviet Union now begin to invest in the requisite new technology for deep space exploration when the United States is already carrying out these missions and making the initial discoveries? In contrast, the U.S. need is to maintain a viable set of programs to complete the initial exploration of the solar system in the coming years. This is an especially difficult task in times of great financial pressure because of the long lead time that is required to develop and instrument reliable spacecraft capable of exceptionally long flight operations.

Both the Soviet Union and the United States early accepted the challenge of exploring the moon and planets with automated spacecraft. Despite differences in style and in level of national space effort, these exploratory missions of both countries continue.

Efforts in space astronomy, however, display very different national priorities. The large, diversified, and profoundly successful observational programs of the United States, both in space and on the ground, are virtually without parallel in the Soviet Union. A major difference in national scientific priorities is indicated in this area (*20*). Consequently, we can find little possible basis for collaboration, and therefore for further elaboration in this article, despite the enormous scientific significance of past achievements in space astronomy and the even greater future potential.

Space Applications

The annual number of successful launchings of spacecraft by the United States and the Soviet Union is given in Table 1. Evidently, the unpublicized Soviet military space effort significantly exceeds that of the United States and is perhaps twice as large as the publicized civilian program. Furthermore, it appears that the civilian program of the United States may be only about half that of its counterpart in the Soviet Union.

Civilian uses of Earth orbit have centered around four main areas: (i) communications, (ii) traffic control and navigation, (iii) meteorology, and (iv) Earth resources. The first two areas of activity have been reduced by the United States, especially, to continuing engineering activities of demonstrated economic value whose principal issues of organization, regulation, and participation are not unique to space endeavors.

The United States has had operational weather satellites for many years, starting with the TIROS (Television Infrared Observation Satellite) series and continuing to the present with the NOAA (National Oceanic and Atmospheric Administration) series. A research and development effort by NASA has continued with the Nimbus, ATS (Applications Technology), and SMS (Small Magnetospheric, Stationary Meteorological, and Synchronous Meteorological) satellites. The Soviet Union now successfully operates a competent satellite system, the Meteor, and has developed an automatic picture transmission (APT) system for selected users. However, the long operational lifetime characteristic of U.S. meteorological satellites still is not exhibited by the Soviet systems. Neither the United States nor the Soviet Union appears to face major policy issues concerning weather satellites; both countries are heavily involved in international meteorological programs such as the Global Atmospheric Research Program (GARP) in which satellite results are a significant component.

The United States launched the spacecraft Landsat 1 (1972) and 2 (1975) to evaluate the many uses of data obtained by remote sensing of the Earth's surface. (Landsat 1 originally was designated Earth Resources Technology Satellite, or ERTS.) Many potential applications of the data have been identified and technical evaluations are well under way. A parallel effort of ocean observation is being initiated with the SEASAT A project, scheduled for launch in 1978.

There have been Soviet papers on the merits of collecting data about Earth's resources from satellites, but no satellites have been launched exclusively for this purpose so far as we know (*21*). It appears that the Soviet Union has not yet mounted a major program to contribute to this area of great international as well as domestic interest.

The Anatomy of Cooperation

The beginning of the 1970's was marked by a major change in relations between the United States and the Soviet Union with regard to space activities. Significant bilateral arrangements were negotiated concerning both strategic weapons and civilian space cooperation. It is our opinion that the change in Soviet attitude which permitted these successful arrangements reflects the space competition of the 1960's in two ways.

First, the Soviet Union probably felt that the two nations had exhibited extensive capabilities in space so that each could make a comparable commitment to cooperative programs. Second, the contrast between the very successful Apollo program and the failures that plagued the Soviet manned space program must have reminded some Soviet leaders of the U.S. potential for accelerated development of advanced strategic weapon systems should the United States feel sufficiently imperiled as a nation to do so.

The move from competition to détente was a dramatic turn of events. The primary initial benefits are political; public displays of cooperation demonstrate an alternative to decades of official antagonism. The Apollo-Soyuz flight can be judged as a major success by these standards, presumably well worth its cost when evaluated in terms of the overall relations between the two countries. On the other hand, the flight does not by itself point out the way to the future. There was no major advancement of U.S. or Soviet technology, nor were the achievements of Skylab or Salyut significantly extended. Additional handshakes in orbit probably would not attract enough public attention to be judged cost-effective even for political purposes. Therefore, space collaboration for the future must be aimed at substantive technical and scientific benefits, as well as political objectives, in order to be in the self-interest of both countries.

Joint space activities may be considered in three categories of successively increasing significance: (i) data exchange, (ii) cooperative experiments, and (iii) joint operations. The United States and the Soviet Union have already exchanged weather satellite pictures, lunar soil and rock samples, and limited Mars data obtained during the 1971 period of simultaneous missions (*22*).

Of the possible joint space activities, data exchange agreements involve the smallest budgets and have least impact on the national space programs and establishments involved. However, to be of maximum significance scientifically, such exchanges require person-to-person communication to elucidate experimental details and idiosyncrasies as well as to compare independent interpretations. In the past, communication between U.S. and Soviet scientists generally has been inadequate. In our opinion, the situation has been aggravated by the limited overseas travel of Soviet citizens, including most key scientists involved in analysis of spacecraft data. Surprisingly, there has been a significant decline in visits to the United States by Soviet space scientists since 1973. Whether this reflects internal tensions within the Soviet Academy of Sciences (which plays a much more direct role in space than its U.S. counterpart) or has a more general explanation is not clear to us.

Another mode of cooperation is for one country to place an experiment aboard a vehicle of another country. An example of this is the French "Stereo" equipment in which a French solar radio emission experiment was flown on the Soviet spacecraft Mars 3, as well as on later flights, for comparison with simultaneous observations on Earth. A French corner reflector for laser ranging was carried on the Lunokhod rovers. United States biological experiments were aboard the Soviet satellite Kosmos 782 which was launched 25 November 1975; its capsule returned to Earth on 23 December 1975 (*23*).

The third category of cooperation, that of joint operations, is the most significant in terms of cost and implications to each other's programs. The Soyuz-Apollo rendezvous demonstrates that joint operations are practical despite differences in language, technology, institutions, and style. More ambitious joint missions, manned or automated, are possible but have not been scheduled thus far.

Collaboration in space can further scientific research in three ways.

1) Exchange of different data on the same subject can be mutually beneficial. Government support of such exchange can be especially significant to space science where the voluminous data can be expensive to reproduce and where, in any case, the data generally are the property of the government, not the individual scientist. The different lunar localities sampled by the Soviet program provided very useful additions to the much more comprehensive U.S. lunar rock collection. Also, exchange of data from U.S. and Soviet Mars orbiters in 1972,

Table 1. Number of successful launches (*30*).

Year	United States		Soviet Union	
	Civilian	Military	Civilian	Military
1971	18	13	21	62
1972	18	13	19	55
1973	13	10	27	59
1974	14	8	26	55
1975	19	9	27	62

before its publication, was motivated by strong mutual interest in entry and surface conditions that were significant to upcoming landing attempts with automated spacecraft.

2) A second benefit of cooperation can be informal communication channels that result in the exchange of ideas as well as greater technological insight. This was one objective of Apollo-Soyuz, although we do not know how successful such communications have really proved to be.

3) Another potentially beneficial result of cooperation on very large, costly programs is the genuine savings to each country that is possible through joint development and operations to achieve clearly desired objectives.

However, there are dangers as well as benefits in cooperation. If either nation is consistently more ambitious (and successful) than the other in space, continued cooperation between the two can lead to "unequal" exchanges. This outcome may be avoided if each pursues separate and distinct activities, so that achievements of one kind cannot be so directly compared with those of another.

Furthermore, to the extent that the United States commits limited space resources to cooperative programs, the opportunity to do other things within a tightly constrained budget may be sacrificed. Missions with long lead times, such as those to the outer planets, could be especially affected.

Finally, there is the U.S. need to preserve a unilateral lead in the technology required for advanced space application; concern over balance of payments gives special significance to this aspect of the U.S. space program.

Future Prospects

The U.S. civilian space program is currently operating under a firm funding constraint of about $3 billion per year which, in view of the high rate of inflation, has recently been equivalent to as much as 10 percent annual decrease in real resources (Fig. 4).

On a longer time scale, renewed domestic support for a larger space effort is

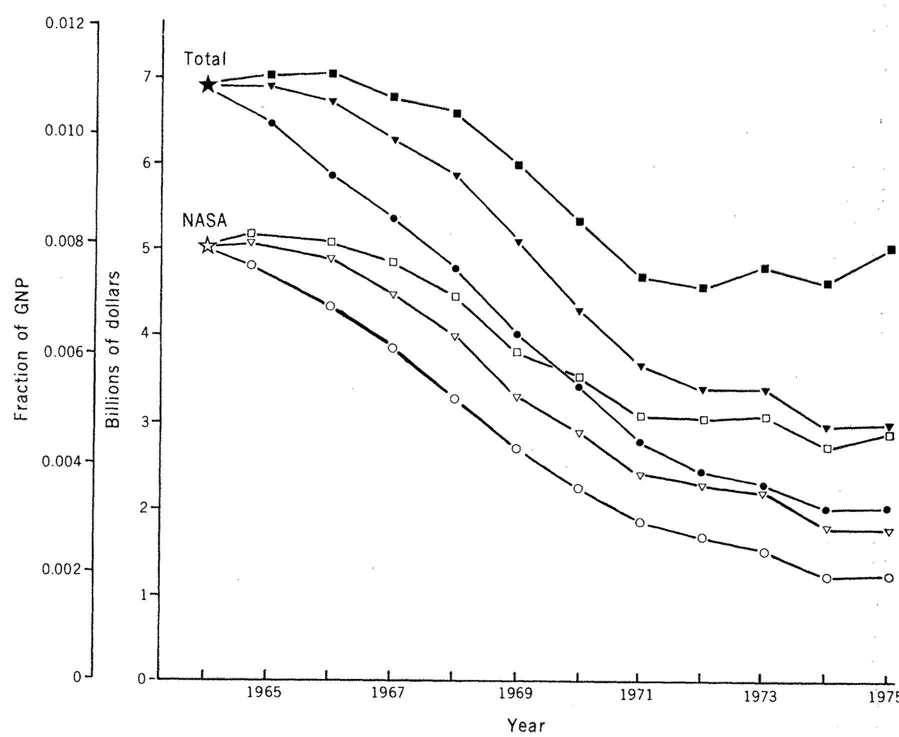


Fig. 4. U.S. budget authority for space is plotted for fiscal years 1964 through 1975. The curves for total allocations include NASA, Department of Defense, and other agencies (principally the Atomic Energy Commission and the Department of Commerce). Within each set the trends indicated by squares represent current dollars, those indicated by triangles are in constant 1964 dollars, and those indicated by circles are expressed as fraction of current gross national product. The values shown for 1975 are preliminary estimates released at the beginning of the fiscal year.

possible, perhaps as part of broad cooperative arrangements with the Soviet Union or other countries. In the short term, however, we believe the more likely prospect would be pressure to include any new cooperative programs within about the same total budget level. Since there is already an overloaded unilateral program, it is difficult to imagine how new large endeavors other than the space shuttle can be accomplished for some years without substantial dislocation of existing priorities and schedule. Furthermore, the high success rate of U.S. efforts in recent years suggests that the main objectives of currently planned programs can be achieved with reasonable confidence on a unilateral basis. Thus it is appropriate to ask what benefits for the United States might be realized through new cooperative ventures.

The Soviet Union, in contrast, continues to maintain a large space effort, as measured by number of launches, number of new missile and space launcher types, and new kinds of space and ground systems, including large tracking ships. We find little evidence that their total space effort has ever declined significantly, although it may well be at a stable level now. The real uncertainty is what this large and enduring space effort will actually achieve. If the Soviet Union is able to solve the space system reliability problem which has so frustrated its ambitious efforts, the achievements could be very imposing indeed and might even include a manned lunar base by the middle 1980's. Advanced automated lander systems, including a rover, could be deployed on Mars by the end of the 1970's; a Mars sample return mission could be a realistic goal. At the same time, an extensive Venus program and diversified Earth applications missions could be carried out. If their present mixture of success and failure continues, we would expect the Soviets to work toward the same objectives but with the time scales slipped significantly in almost every case. On the other hand, if space system reliability worsens and if a few more catastrophic failures in the manned program occur, it is conceivable that program objectives may have to be reduced regardless of current intentions. Soviet planners surely must recognize their problems and are realistically examining their options.

How can further collaboration in space serve their interests? Do U.S. and Soviet interests in space overlap significantly?

With regard to future manned space activities, we would suggest that genuine mutual interest may arise from the U.S. desire to avoid increased space expenditures and the Soviet need to ensure greater success. If the Soviets, on their own, overcome their difficulties with large manned systems, the United States may feel pressure to respond to the prospect of enhanced Soviet manned activities. Any resumption of large-scale manned activities in the immediate future would distort both a balanced U.S. space program and federally sponsored programs in advanced technology generally.

Hence advocates and adversaries of manned space flight alike might view major collaboration as in the U.S. self-interest. The principal themes of each country's new civilian efforts could conceivably be developed in complementary fashion. The shuttle could be configured to permit operations in conjunction with a new large Soviet space station, perhaps in the early 1980's. This division of developmental effort would permit the Soviet Union to concentrate on the design and test of the stations without the need for a new launch vehicle capability beyond the existing Proton system. The shuttle could be used for crew changes and would have a great advantage over Soyuz in the number of men and amount of equipment and expendables it could carry. However, the Soviet Union would retain a unilateral transportation capability in the Soyuz. Such substantive long-term collaboration with the United States in new manned space activities would seem to afford Soviet managers and engineers an opportunity to overcome more quickly their reliability problems through exposure to successful U.S. procedures and practices (*24*). And since both nations would have access to the station on a continuing basis for intensive experiments conducted by men, real savings might be possible for the United States. Such a joint program could become the principal manned space activity for both nations.

If joint U.S. and U.S.S.R. space station activities were pursued in the early 1980's, a more distant goal might be renewed manned exploration of the moon with a permanent station in Earth orbit as an integral step. Indeed, "conventional" concepts of manned lunar operations suggest an Earth-orbital transfer point à la *2001: A Space Odyssey*. The United States could bring the technology of life support and spacecraft systems that have already been proved in lunar operations to such a future joint endeavor. The Soviet Union could take the lead in development of new transportation from Earth orbit to lunar orbit, which would be assembled and fueled in Earth orbit. Finally, the United States could retain the option for a shuttle-based lunar transportation system of its own as an alternative to use of a Soviet one. Such a program might be targeted to begin lunar operations in the late 1980's, thus delaying development expenditures until after the completion of the shuttle, as is consistent with the desire for a balanced and evenly funded U.S. space program. Similarly, the Soviet Union could substitute the expectation of joint manned lunar activities in the future, perhaps preceded by an aggressive automated exploration program, for their currently poor prospects after the Apollo success.

Broadened international participation in renewed manned lunar exploration would also be a future option for the United States and the Soviet Union. In such an optimistic and speculative scenario, there could be a genuine analogy between manned exploration of the moon and of the Antarctic; the initial nationalistic race is succeeded, decades later, by a coordinated international scientific research program (*14*, p. 120).

An even more extraordinary extension of U.S. and Soviet collaboration in manned Earth orbital activities is conceivable. It could become technically credible for a U.S. president and a Soviet premier, in, perhaps, 5 years (if joint operations from a shuttle base were really imminent), to commit their countries to a joint program of manned planetary flights beginning about 1990. Just as the initial manned lunar exploration came about prematurely as a consequence of national rivalry, so might man's first flights to another planet offer a visible symbol of joint leadership if détente proceeds toward a genuine economic and political rearrangement. In fact, it is only as a consequence of special political alignments that we foresee manned planetary exploration before the end of this century.

What about further collaboration in automated scientific missions? Could unilateral objectives be served by bilateral cooperation in that area of endeavor as well? Ample opportunities for data and experiment exchange, which need not have a significant technical impact on mission style or complexity, appear to be possible in automated lunar and planetary exploration. It would seem most desirable for U.S. experiments to be flown on Soviet lunar and Venus missions. The United States could offer similar opportunities in missions to outer planets (and perhaps in some new missions to the inner planets), in addition to data exchange and joint data reduction with the Soviet scientists.

A more speculative and ambitious venture might capitalize on the recently demonstrated Soviet capability to place a substantial payload into the atmosphere of Venus and to maintain communications with it. Conceivably, the Soviet system could be used to deliver and maintain a long-lived "submersible" scientific station, perhaps with the capability for extensive vertical movement through buoyancy modification. In a joint venture, the United States might take responsibility for development of the new "submersible," and both nations would supply scientific instruments for it.

Mars constitutes a more uncertain subject. The United States has made most of the contributions to the exploration of Mars, yet U.S. budget limitations and space priorities point to a hiatus in Mars missions for the rest of the decade. There is no indication whether the Soviets intend to renew their high rate of Mars launchings when the launch energies become more favorable again in 1979. It is against this uncertain background that a joint mission of great scientific significance has received some technical analysis, that is, the use of automated spacecraft to return samples from the surface of Mars to Earth. Each country could contribute essential flight hardware and mission operations support. The Soviet Union has already carried out a sample mission to the moon (Luna 16 and 20). However, sample return from Mars requires difficult new technological developments in order to provide, among other things, for exit from the martian surface through its atmosphere. In addition, there is concern over "back-contamination" and how to deal with it (*25*). The Viking life detection experiments and the gas chromatograph and mass spectrometer presumably will help place this nebulous topic on a more substantial footing.

A judicious blend of U.S. and Soviet capabilities probably could produce an important mission. However, it might be difficult to formulate a Mars sample return mission at a low enough cost to the United States to avoid materially weakening other excellent U.S. scientific programs, unless supplementary funding were made available. Nevertheless, we believe that sample return from Mars is the most significant future planetary mission that is technically feasible; it offers a qualitatively different and intellectually challenging goal for planetary exploration.

There is a more modest possibility for a joint martian mission—delivery and operation of a small automated vehicle for remote traversing. In this case, the U.S. Viking system, assuming successful performance next summer, might be considered for delivery of a Soviet "Marsokhod" (as it has been termed in one Soviet article) that is developed as an extension of the Lunokhod, which was successfully operated for many months on the lunar surface. However, any mobile vehicle for delivery to the martian surface would have to be smaller and lighter than those used on the moon. Both nations could instrument the vehicle. Thus, for both Venus and Mars, a logical next step could be joint developments to provide surface mobility at substantial cost savings to each country.

Conclusions

Findings about Earth, the solar system, and the cosmos, made in conjunction with space exploration, have been among the most important scientific discoveries of the last two decades. There is every reason to expect an equally rewarding future for space science if there is an orderly progression in capability to (i) reconnoiter more distant parts of the solar system, (ii) investigate Earth's nearby planetary neighbors in more detail, and (iii) place larger astronomical telescopes in orbit. Man's outward reach from his own planet in the second half of the 20th century has been a unique and positive cultural activity which will have lasting impact on the human race. The United States has led the process of intellectual discovery and can continue to do so.

However, esoteric scientific discovery in space has been, and seems destined to remain, dependent on broader social objectives and activity. There must be a vigorous program of space flight and technological development for diverse purposes if major scientific discovery in space is to continue. In addition, there must be popular enthusiasm for intellectual (and sometimes human) adventure; a completely utilitarian program, even of substantial size, probably would not form a satisfactory umbrella for major scientific efforts.

The space efforts of the United States and the Soviet Union have been closely linked, first through rivalry and more recently through cooperation. This interdependence has served to stimulate both societies as well as to influence the character of individual programs. The Apollo program proved to be a creative mechanism to translate the fear and enmity created by the image of a Soviet Union capable of launching missiles and satellites into a high adventure of historic significance and, incidentally, of enormous scientific value, especially in regard to the returned lunar samples. The Apollo-Soyuz flight, although modest by comparison, nevertheless constituted the major U.S. space effort for the past few years and dramatized the mutual political change away from dangerous confrontation.

From whence will come future impulses to rekindle national curiosity and excitement in reaching out to explore Earth's environment? Is renewal likely to be brought about by internal political and social processes within the United States?

Certainly if a compelling new idea emerges which requires the use of space technology in its pursuit, popular interest could be stimulated. For example, if the Viking landers were to positively detect indigenous life forms on Mars, broad public support could be expected for new missions to elucidate the nature of that first sample of alien life.

Another endeavor that might elicit broad popular support would be the search for evidence of intelligence elsewhere in the universe. To the extent that such a search involved the application of space technology, it could perhaps afford the means of a dramatic renewal of interest in esoteric space activities. Many scientists think it is likely that there are intelligent societies elsewhere in the galaxy. There is great uncertainty, however, about the cosmic density of such inhabited stellar systems and therefore about the probability of successful search efforts. Accordingly, this endeavor is not likely to become a major national activity without additional observational information that leads to a more definite estimate of success (*26*).

Space colonization has been discussed considerably in recent years, both as a possible focus for popular imagination and adventure and as a supposedly practical response to societal needs (*27*). It is our view that space colonization is not possible in the short term and will not be practical for many years to come (*28*). Thus, we do not foresee the goal of space colonization as a credible stimulus for renewal of U.S. space efforts. In general, we find it difficult to identify any new internal trends or circumstances which are likely to counter the seemingly inexorable pressure to restrict exciting new space research.

However, interrelationship with the Soviet space effort might play an important role in stimulating the level of activity and fashioning the character of U.S. space efforts. A cooperative and complementary development of the U.S. shuttle transportation system for use with a large Soviet space station program is one interesting possibility that is apparently already under discussion (*29*). Also, the automated return of a sample from Mars could become an important joint program. Both of these efforts would require greater collaboration, technical innovation, and flight system integration than did Apollo-Soyuz but, to us, do not constitute a much more difficult new step. Collaboration on a Mars rover or Venus "submersible" mission need not strain either the U.S. budget guidelines or the space technology of either country.

What about other nations? What about collaboration between the United States and Western Europe, for example?

Such relationships can develop concurrently with a strong bilateral commitment between the United States and the Soviet Union and may even benefit accordingly. In the future, a multinational program is possible in Earth orbit—even on the moon—but only as long as the United States and the Soviet Union themselves collaborate to provide the basic transportation and housing in space. Western Europe, although its gross national product exceeds that of either the United States or the Soviet Union, has consistently expended very little on space research. We see little evidence of a change in the relative indifference of Western Europe to major (and costly) space efforts. Therefore, we do not consider that future U.S. space collaboration with Western Europe (or other nations) can in any way be comparable to or substitute for U.S. and Soviet space collaboration, although it might be a very important complement to the overall effort.

Finally, we wish to reiterate that person-to-person relations between Soviet and U.S. scientists must be fostered if there is to be the true scientific flowering that can and should accompany détente. Progress must be made toward more intercommunication and openness if détente is to be meaningful to American scientists. The rate of progress in space science may well be dependent on the political fortunes of détente on Earth.

References and Notes

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31. J. Anderson prepared the data for Fig. 4. We thank W. R. Adey, J. Bruman, J. D. Burke, P. K. Eckman, T. Owen, R. J. Parks, C. Sagan, and C. S. Sheldon II for constructive criticism of the manuscript.