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International Cooperation in Space

A wide variety of joint projects contribute to science and have practical applications.

Arnold W. Frutkin

As a widely endorsed political and scientific objective, international cooperation in space deserves something better than its usual quota of abstractions, moral imperatives, and contrived prescriptions. Space collaboration among nations has a history, established practices, and broad opportunities, as well as real-world requirements and limitations. Any serious investigation of the subject should quickly dispose of the naive assumption that cooperation in space is not energetically sought and practiced and should bring some appreciation of the governing circumstances, which are especially evident in foreign budget limitations and political constraints.

In fact, cooperation among nations in space matters exists on several levels and with varying degrees of scientific, technical, economic, and political significance. One of its more substantive manifestations is in the international programs of the National Aeronautics and Space Administration (NASA) (*1*). This article confines itself to NASA programs, but, even so, it is only possible here to suggest by a few examples the scope of the space agency's international activity.

NASA's work with foreign agencies and scientists is authorized by a specific directive in the Space Act of 1958 (*2*). The legislative record of that act indicates broad support for the provision that the space programs of the United States include cooperation with other nations—to demonstrate peaceful purposes, to profit from foreign scientific and financial contributions to common space objectives, and to share the resulting benefits. That support has very probably grown in the succeeding years and is much in evidence today, as often in the popular press as in congressional debate (*3*).

Strenuous efforts by NASA to breathe life into these purposes of the Space Act have produced a wide range of projects in which significant scientific, engineering, and funding responsibilities for space missions have been assumed by other nations [see (*4*) and Figs. 1–3]. In a relatively short period of time (when the requirements of space development are considered), these projects have engaged scientists in over 70 nations and have generated more than 225 agency and executive agreements with over 35 countries; they have covered specific flight, flight support, and other programs.

Television Instruction for India

The latest and possibly the most exciting product of NASA's international program is an agreement reached last 18 September with the Department of Atomic Energy (DAE), parent agency for space activities in India. The agreement provides for an experiment in the broadcasting of instructional television via satellite to some 5000 remote Indian villages (*5*). The basis for India's urgent interest in such an experiment is apparent enough. India today possesses a single television transmitter, located in New Delhi. A substantial proportion of her half-million villages are so isolated that the government has no effective means of communication with their largely illiterate inhabitants. Yet national programs to develop population controls and to increase agricultural productivity require immediate and effective assistance through local instruction and education.

The experiment is made possible by advances in NASA's series of Applications Technology Satellites (ATS). The ATS-F satellite, to be launched in 1973, will increase on-board power to 80 watts, will achieve high gain by means of a 9.1-meter parabolic antenna to be deployed in space, and will point the antenna with extreme precision. These features will make it feasible for the first time to broadcast television directly into the viewing set. The receiver must, however, be augmented by the addition of a preamplifier, a modulation converter, and a parabolic antenna with a diameter of about 3 meters. The total cost of such a receiver-viewer is expected to be a few hundred dollars.

The combination of ATS-F satellite and augmented receiver will bring television directly into the villages without a costly intermediary network of large ground terminals and microwave links. (Actually, the India experiment will be a hybrid one, since it will be less expensive where villages are densely clustered to use ground-relay stations for distribution of satellite programs to conventional receivers.)

The September agreement provides that NASA will make ATS-F available to India for a year of broadcasting devoted to family planning, agricultural improvements, national integration, and other educational programs. The satellite will first be used for a few months

The author is assistant administrator for international affairs, National Aeronautics and Space Administration, Washington, D.C., and adjunct professor of international studies, Center for Advanced International Studies, University of Miami, Coral Gables, Florida.

by U.S. agencies to perform about 18 experiments in communications development and environmental factors. Then it will be nudged farther east in its synchronous orbit, until it comes into line of sight of an existing experimental ground station at Ahmedabad. That station and perhaps others will transmit television programs, *formulated and controlled by India,* to the satellite for rebroadcast to village receivers and to three relay stations. The programs will go out on one video and two audio channels. Thus, simultaneous broadcasting in two languages will be possible. If two or three regions use the service at different periods of the day, such time sharing can increase this to four or six languages.

Since the contributions of the United States to the Indian experiment will be made in the course of a program already in process for technological development purposes, it entails only modest incremental cost to NASA. The satellite transponder for the Indian experiment and the relocation of a small ground-control station together represent little more than 1 percent of the total cost of the ATS-F and ATS-G projects (which are combined in NASA's programming). The cost to India for the development and conduct of the experiment may exceed $15 million—most of which can be met in rupees. Under the agreement, each side is responsible for its own costs.

India's programmatic responsibilities are clearly substantial. They include the operation of the Ahmedabad station; the construction and operation of relay stations; the design, production, distribution, and maintenance of receivers; the development, scheduling, and production of effective television programs; the organization of village audiences and provision for their access to the equipments and supplies whose availability is implied by instructional programs; and more. The effort can hardly avoid stimulating substantial industrial and managerial progress of broad value to India—in addition to attacking the immediate objectives stated in the cooperative agreement.

It should be of some practical interest to those interested in international cooperation that the U.S.–India instructional television agreement required about 4 years to progress from concept to signature. An important element in its extended history was a year-long joint study to assess the relevance of the experiment to a national television system which India might later establish—based either on satellites or on conventional ground-distribution links. This study convinced India that it can save one-half to two-thirds by selecting the satellite alternative. Thus, a fixed annual expenditure will give India a national communications system covering all its communities in 10 rather than the 30 years required for conventional television links.

Something should be said regarding the fundamental premise that television instruction can fulfill the key social role expected of it by India and by other developing countries. To test the premise, India has conducted a preliminary experiment in the Delhi area over the past 2 years. The existing Delhi transmitter was used for biweekly broadcasts on agricultural productivity to conventional receivers in some 80 nearby villages. The program was then evaluated against experience in control villages lacking television receivers. The Indian Committee for Space Research has published findings that strongly support the assumption that, *for illiterate adult audiences*, such programs are indeed more effective than communications through other media. During the course of this early test, the writer attended an evening broadcast in one village where some 400 inhabitants of all ages watched a broadcast on the use of new seeds and fertilizers. Audience interest, enthusiasm, and impact were evident. In harder terms, the village elders reported that the broadcasts had increased their incomes. They complained only that the programs were not offered frequently enough.

The U.S.–India experiment in instructional television by satellite will be closely watched by other developing countries and by those Westerners who hope that advanced technology can be of some use in attacking larger social problems in the developing world. Brazil, for example, has also expressed interest in the use of community broadcast satellites to complement a larger national education program, and the DAE has invited Brazilian observation and participation in the India experiment. A United Nations Working Group on Direct Broadcasting has en-

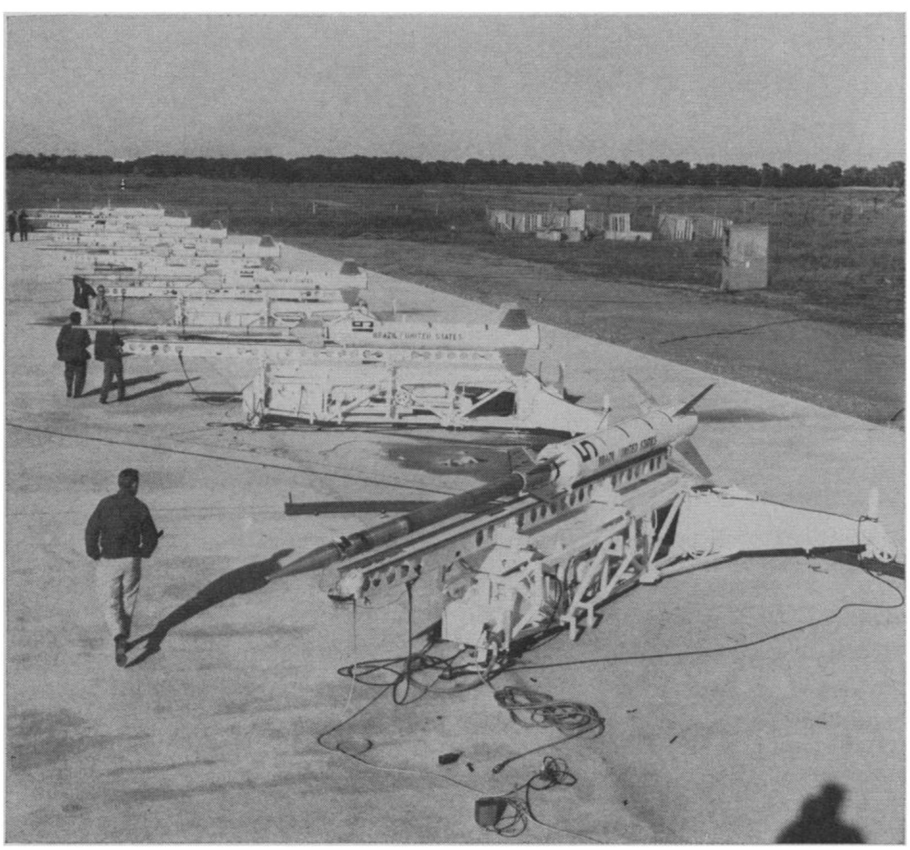

Fig. 1. Sounding rockets and experiments in final stage of inspection before launching from the Casino range in Brazil. This cooperative project between the Brazilian National Space Commission and NASA was undertaken in connection with the solar eclipse of November 1966.

couraged experiments of this type and will undoubtedly follow this one carefully (*6*). The experiment may also establish a valuable precedent for the proper use of direct broadcasting capabilities and may help to direct present concerns over possible abuses into constructive channels.

Resource Surveys by Satellite

Some results of relatively simple photography from NASA's Mercury, Gemini, and Apollo spacecraft and of imaging from meteorological satellites have inspired proposals to use better equipped spacecraft for regular surveys of earth resources. For example, satellite-borne, multispectral cameras and infrared sensors might have value in the monitoring and management of crops, including the detection and control of crop disease; the survey and management of water resources; the detection and control of erosion and pollution in river, harbor, and coastal areas; the observation of forest fires and the monitoring of forestry practices; the collection of geological information of possible utility in mineral prospecting; the monitoring of fishing grounds and sea surface conditions; and mapping on an economic and current basis (*7*). At the same time, there is a recognized need to preserve caution in promoting the promise of earth surveys by satellite until that promise can be validated through experience with the first spacecraft dedicated to that purpose.

With these prospects in view, NASA has framed a twofold earth resources survey (ERS) program: (i) a current aircraft phase for the testing and calibration of sensors over known surface features so as to establish data recognition patterns, or "ground truth," and (ii) a future satellite phase in which systems for the acquisition of earth resources data from orbit and for the processing of such data will be developed and tested.

The prospects for international interest, participation, and benefit in a successful ERS program are obvious, particularly for the developing regions. There are some who expect political reservations by countries whose territories could be covered by earth-surveying satellites, but there is much more reason to discount than to emphasize such concern (*8*). Those who advocate caution in forecasting the ultimate economic gains are perhaps on sounder ground. Technological success in the acquisition of resources information cannot in itself assure effective economic application of that information. Application must, of course, rest always on imperfect social mechanisms.

In this ambivalent situation, there is a clear call for restraint to avoid stimulating other countries to premature or excessive commitment of scarce funds and skills. At the same time, it has seemed desirable to signal, through appropriate preliminary activities, the prospect of a significant new aid to national development. The principal example of such a preparatory project in the international area is NASA's arrangement with Brazil and Mexico in the aircraft phase of the ERS program. These arrangements are predicated on the inherent economic utility of aircraft sensing programs. They should help to develop the skills and ground truth necessary for the use of satellite data, when it becomes available, but they do not depend on the realization of satellite techniques.

Agreements between NASA and space agencies in Brazil and Mexico (with participation by numerous user agencies in all three countries) were signed in 1968. Implementation of these agreements has been prompt and effective. From February to June 1968, 12 to 15 managers, scientists, and engineers from each country were trained at NASA's Manned Spacecraft Center in Houston in field work with user agencies and at a special course organized at the University of Michigan. Five Brazilian test sites were overflown by one of NASA's two instrumented aircraft in July 1969. Six Mexican sites were overflown in April 1969. A preliminary joint review of the Mexican data took place in September 1969 in Mexico City. The Brazilian data were reviewed last January. Domestic aircraft surveys are planned by both Mexico and Brazil for 1970.

The Brazilian and Mexican projects, in addition to the values inherent in both, testify to the open character of the earth resources interests of the United States and can serve as showcase examples of sound preparatory activity for other developing countries. (Brazil has, in fact, invited Indian observers to participate in the earth resources program described here.) Besides introducing new capabilities into Brazil and Mexico, the efforts of these countries and the United States together

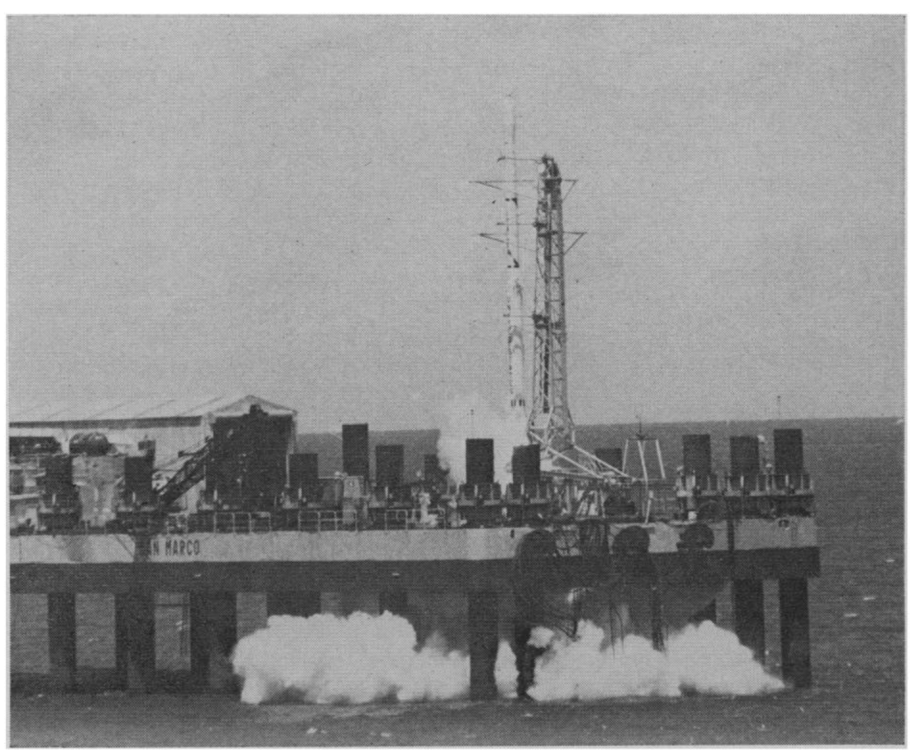

Fig. 2. The Italian San Marco B spacecraft being launched from a platform at sea off the coast of Kenya on 26 April 1967. The satellite was designed to obtain continuous equatorial air density measurements. The project was carried out under a cooperative international agreement between the Italian Commission for Space Research and NASA.

add to the variety of surface features that have been calibrated for reference in future satellite programs. The early results have, according to reports, already prompted Mexico to switch from black-and-white to color photography in current conventional aerial survey programs.

In the wake of the Brazilian and Mexican agreements, Indian agencies have undertaken a similar domestic aircraft program, with advice and assistance from NASA. An immediate practical application was identified: a coconut palm blight of unknown extent had been detected in Kerala State in India. An Indian aircraft was instrumented and has already surveyed the region to map the spread of the blight by means of infrared or color film techniques; informed countermeasures can now be taken. Technical expertise developed through a NASA-supported university program in the United States is being made available.

In his September 1969 speech to the United Nations General Assembly, President Nixon singled out for special mention the prospects of earth resources benefits through space techniques. He promised that the United States will make the data of its future programs available to all and will work toward ways to provide for international participation *"as this program proceeds and fulfills its promise"* (stress supplied). The statement reflects the caution that will be required until satellite techniques are validated in the first limited missions of 1972 and 1973 and until subsequent satellite projects are defined and funded which could make ERS data available on a global and operational basis.

Joint Satellite Programs

International cooperation of a very different character has been extended by NASA programs in the form of joint satellite projects with the United Kingdom, Canada, Italy, France, Germany, and the ten-nation European Space Research Organization (ESRO). A dozen foreign satellites have already been launched successfully by NASA in joint space research efforts. An equal number are in progress under existing bilateral agreements. The most ambitious is a cooperative project of NASA and the German Ministry for Science and Education. This is the $100-million Helios project for the preparation and launching of two probes to within 45 million kilometers of the sun.

Germany will design, manufacture, and integrate the two spacecraft, provide the German experiments (which constitute the bulk of the payload), operate and control the spacecraft from a German control center, and provide data to all the experimenters. NASA will provide two advanced launch vehicles of the Atlas/Centaur or Titan/Centaur class, certain experiments, coordination with Italian and Australian co-experimenters, and the use of the NASA deep-space network to support the mission. The spacecraft will weigh about 205 kilograms each and will be launched into heliocentric orbits in the 1974–76 time frame.

The Helios project is the German response to suggestions by a NASA team traveling in Europe in 1965 to propose more significant cooperative space projects than had yet been engineered. Agreement in principle was reached in 1966; a year later, a Joint Mission Definition Group began a 2-year comprehensive study. The group's final report in April 1969 led to the signing of a memorandum of understanding in June.

The Helios spacecraft impose technical requirements of an advanced character on German industry, particularly for the development of the on-board power system and thermal controls, which must cope with radiation at the level of 11 solar constants. On-board data-processing systems must also be highly sophisticated. The scientific payloads themselves will be contributed by a large group of experimenters, who represent 12 universities and government laboratories in Germany, the United States, Italy, and Australia.

The Helios probes are designed to fly closer to the sun than the planet Mercury—and thus to contribute importantly to an understanding of solar processes and solar terrestrial relationships. They will investigate the spatial gradient of the interplanetary medium, the interplanetary magnetic field, and the density, temperature, velocity, and direction of the solar wind. The Helios experimenters will study discontinuities and shocks in the interplanetary medium both magnetically and electrically. They will study in situ, as it were, the electron plasma oscillations believed responsible for type III radio bursts and other wave-particle interactions, the propagation of solar cosmic rays and their spectral composition, the spatial gradient of galactic cosmic rays and interplanetary dust, and the dynamics and chemical composition of the dust. The x-rays emitted from the far side of the sun will be monitored when the probes are in or near superior conjunction with the sun. Supporting ground observations will be made from the earth. Finally, the Helios probes' high eccentricity and close approach to the sun will provide an opportunity for study of the quadrupole mass distribution of the sun and relativity effects. It should also be possible to improve estimates of the mass and orbital elements of the inner planets—a task that will require the most precise spacecraft ranging.

As in all of NASA's cooperative satellite projects, Helios will be managed by a Joint Working Group, which will concern itself with all aspects of technical implementation but which will focus primarily on payload-spacecraft and spacecraft-booster interfaces. The Joint Working Group is an important and tested mechanism for ensuring full and successful cooperation. Another standard feature of the space agency's cooperative arrangements is that there be no exchange of funds between the participants; each will bear the full cost of his agreed responsibilities.

A quite different example of cooperative satellite enterprise is the French Project Eole. The French National Space Commission (CNES) is building a small satellite, to be launched in late 1970 or early 1971, which will operate in conjunction with some 500 constant-level balloons in a pioneer program to map the global wind circulation. NASA will use a Scout booster to launch the Eole satellite into a low-inclination orbit. The French are developing and will furnish the balloons. They will launch these balloons, with assistance from Argentina, in various latitudes in the Southern Hemisphere. Each balloon will carry an electronic package to provide a distinctive signal. The satellite will identify and locate each balloon, deriving its path from a series of electronic interrogations and obtaining additional information on pressure, temperature, and balloon superpressure.

In the hope of achieving balloon lifetimes of at least 90 days, the French have supported extensive developmental work, which has significantly advanced balloon technology. CNES has recently reported that several constant-level balloons have successfully flown for 200 days. This capability will be important to the projected Global Atmospheric Research and World Weather Watch programs of the World Meteorological Organization and the International Council of Scientific Unions. Effective systems for launching balloons in large quantities under difficult field conditions have also been developed by the French.

To meet international standards for avoiding aircraft hazards, significant technical progress has been made to reduce the mass of the sensing equipment suspended from the balloons. In the process, unique logic was developed for the sensors and new procedures were devised for testing the hazard that the sensors might represent to aircraft windscreens. (The Federal Aviation Agency became an interested observer of these tests.) The French have also pioneered new approaches to the structural design of spacecraft, which could reduce the rigorous environmental requirements now imposed on experimental payloads. As in Project Helios, each participant bears the costs of its assigned responsibilities.

The development of satellites for marriage to U.S. boosters is not yet, of course, within the grasp of many countries. However, another dimension is added to the possibilities for cooperation through NASA's "Opportunities Program." In essence, NASA opens its own spacecraft to foreign experimenters. Invitations to propose experiments for specific missions are widely distributed both here and abroad. The responses not only broaden foreign participation but have the happy effect of enlarging the body of experiments available for review and selection on their merits. As a consequence, major foreign experiments fly on many of NASA's larger scientific satellites.

The possibilities for ground-based experiments are equally, if not more, important. For instance, in the early 1960's, 11 countries built and installed large and small ground terminals in order to participate in the pioneer intercontinental testing of the first communications satellites, Relay and Telstar. These successful experiments and the relationships engendered by them undoubtedly smoothed the way toward the later organization of Intelsat, the 75-nation consortium for satellite communications.

Lunar Surface Sample Analysis

The most recent and perhaps best publicized example of ground-based international cooperation is in the analysis of lunar surface samples retrieved by the Apollo astronauts. Lunar materials from the Apollo 11, 12, and later missions have, at this writing, been committed to some 193 analysts, 54 of whom represent Australia, Belgium, Canada, Czechoslovakia, Finland, France, Germany, India, Italy, Japan, Korea, Norway, South Africa, Spain, Switzerland, and the United Kingdom. The sample distribution is made on the basis of proposals screened for their merits. The opportunity to make proposals has been widely advertised and is open to scientists everywhere.

Fig. 3. ISIS-A in position for launching from the Western Test Range, Lompoc, California. ISIS-A (International Satellite for Ionospheric Studies) was launched on 29 January 1969 as the third Canadian ionospheric satellite and the second of five satellites in a cooperative program between Canada and the United States. It continues the study of the ionosphere from above (topside sounding) successfully begun with the Alouette 1 satellite.

NASA has, in fact, opened almost all its space program activities to international participation. Some 20 countries have for years collaborated in a wide variety of scientific sounding rocket programs, which have, for the most part, utilized U.S. rockets. Foreign nationals have participated extensively in overseas tracking and in data acquisition. (They operate NASA stations in Australia, Canada, South Africa, Spain, and the United Kingdom entirely on their own.) U.S. weather satellites carry an automatic picture transmission (APT) system, which permits over 50 countries to receive daily weather data directly on inexpensive APT receivers. Possibly the most extensive system now extant for the international exchange of information has been established by NASA and ESRO. The basis for the collaboration is NASA's Scientific and Technical Aerospace Reports (STAR), in which technical reports are indexed and abstracted every 2 weeks. NASA and ESRO collect reports in their respective geographic regions (and elsewhere), index and abstract them according to a common system, reduce them to the same microfiche pattern, and put the total on computer tapes, again utilizing a common system. The combined index and abstract outputs are published in STAR, and the microfiches and computer tapes are exchanged. Thus, a single notification and abstract program supported by ESRO and NASA serves the European and American scientific and technical communities and provides microfiche and computer search services. The technical information divisions of both agencies have the exchange arrangements under continuous review in an effort to expand and improve them.

Limits to Cooperation

The activities illustrated here require no exchange of funds, no export of dollars. Such a program of literal cooperation—as distinct from an "aid" program—assumes some capacity on the part of the collaborating countries to undertake meaningful portions of any joint effort. Clearly, such capacities will in practice be limited by technical, economic, or political factors. Certain of the technical factors are relatively easy to overcome through training programs, which NASA offers in several forms. The economic and political limitations can be more difficult obstacles to cooperation.

Indeed, the United States' most likely and most promising space collaborator, Europe, is sharply restricted by low space budgets. The combined space expenditures of all "third countries" only slightly exceed $300 million per year, less than a tenth of NASA's reduced budget. Herman Bondi, director-general of ESRO, has called it "Europe's ha'-penny space program." Moreover, this limited funding is divided among national, regional, and cooperative programs. As a consequence, although the cooperative programs of the 1960's were far more successful and fruitful than might have been anticipated, they did not extend to European participation in the central aspects of the largest and most costly of the U.S. space projects, the manned flight program. Collaboration with Japan has been considerably more limited, in part by budget constraints in Japan and in part by an earlier decision by Japan to go it substantially alone. Both these constraints may be changing.

The other major gap in space cooperation is found in the political arena. Efforts to engage the Soviet Union in joint projects date back to early conferences anticipating the International Geophysical Year of 1957–58. A brief period of apparent progress began in 1962 with correspondence between President Kennedy and Chairman Khrushchev. The few coordinated projects that the Soviet Union was then willing to undertake have been disappointing in their implementation (*9*).

The subsequent record contains a long list of additional initiatives from the United States, which range from invitations to Soviet officials to visit major launchings to specific proposals for substantive joint space research projects and operations. The most recent NASA overtures have included invitations to the Soviet Union to join in the analysis of lunar samples, to utilize the laser corner reflector positioned on the moon by the Apollo 11 astronauts, to send representatives to a planning conference on unmanned Mars landers, to coordinate the two nations' planetary exploration programs, to join in the "Opportunities Program" described above, and, as stated many times over the years, to submit any proposals that it wishes us to consider. In recent remarks on the Senate floor (*10*), Senator Pastore said:

> . . . let the record not go unnoticed that we have already tried twenty times to engage the Russians in a cooperative effort with relation to the exploration of space. After all, as the Senator from Nevada said not too long ago, "It takes two to tango." And we cannot have this cooperation until Russia agrees to it. That has been our problem right along.

Can these economic and political gaps in cooperation be closed? With respect to the level of western participation, in late 1969 and early 1970 the administrator of NASA undertook a series of visits to major foreign centers in Europe, Canada, Japan, and Australia to put before science ministries and space officials the planned character of the U.S. national space program in the next two decades. These briefings, followed by unprecedented opportunities to participate in NASA planning reviews and design studies, are intended to put foreign officials in a position to consider the implications of future U.S. programs for their own plans and the possibilities for major participation in such future U.S. projects as the reusable space shuttle and the space station (see *11*). (It has also been made clear, through the wide distribution of the NASA report to the President's Space Task Group last September and in additional ways, that programmatic participation of this kind could very naturally entail foreign astronaut participation.)

Whether these overtures will succeed in prompting new thinking with regard to space budgeting in Europe and elsewhere in the West, so that substantial participation can develop, will not be known for some time. With respect to space cooperation with the Soviet Union, NASA continues regularly to put new opportunities before Soviet officials. A two-way correspondence is again under way and may, with improvements in the general ambience, lead to some progress.

Summary

NASA has developed an extensive program of international cooperation, which opens the entire range of its space activities to foreign participation and benefit. The program has involved developing as well as advanced countries in activities that are fruitful scientifically, technically, economically, and (it may be hoped) politically. "Gaps" or limitations in the program are found in the areas of manned space flight and large booster development and in cooperation with the Soviet Union. In the first case, the low level of European budgeting is the prime explanation, perhaps reflecting Europe's late start in the space business and an early underestimate of its values and possibilities. In the second case, the explanation seems to rest with Soviet political views rather than with technical problems or any lack of interest by the United States. Openhanded efforts are currently under way to raise the level of foreign participation in the space programs of the next decade, but it is too early to estimate their chances of major success. Public commentary could undoubtedly assist these efforts more effectively if it were directed more clearly to the actual sources of restriction on foreign participation. Despite the restricting factors abroad, however, there is every reason to persevere with existing and improved programs for international cooperation.

References and Notes

1. Other international space activities are sponsored by the regional European Space Research Organization and the European Launcher Development Organization; the international Committee for Space Research (COSPAR) of the International Council of Scientific Unions; the 75-nation commercial communications consortium, Intelsat; the U.N. Committee on the Peaceful Uses of Outer Space; "specialized agencies" of the United Nations such as the World Meteorological Organization, the International Telecommunications Union, and the International Civil Aviation Organization, whose respective responsibilities are the multinational use of weather satellites, the assignment of radio frequencies for space use, and the future exploitation of satellites for air traffic control and navigation in the operation of the world's airways.
2. The National Aeronautics and Space Act (1958), sections 102 and 205.
3. See, for example, the discussion between Senators W. Proxmire and J. O. Pastore [*Congr. Rec.*, 10 November 1969, p. S14027]. See also, for example, the lead editorial in the *New York Times*, 9 March 1970, p. 34.
4. An almost complete listing of cooperative international projects developed by NASA can be found in a small semiannual brochure entitled "NASA International Programs" (available from the Office of International Affairs, NASA, 400 Maryland Avenue, SW, Washington, D.C.).
5. "Memorandum of Understanding," signed by Vikram Sarabhai, chairman of the Indian Department of Atomic Energy, and Thomas O. Paine, administrator, National Aeronautics and Space Administration, 18 September 1969.
6. *Report of the Working Group on Direct Broadcast Satellites* (U.N. Document A/AC.-105/51, 26 February 1969), p. 3.
7. National Academy of Sciences, *Useful Applications of Earth-Oriented Satellites: Report of the Central Review Committee* and *Summaries*

of *Panel Reports* (Washington, D.C., 1969).
8. The unrestricted use of outer space for peaceful purposes is assured by the U.N. Treaty on the Peaceful Uses of Outer Space; both the United States and the Soviet Union are officially committed to space-based earth resources programs; some 60 nations participated in the Conference on the Peaceful Uses of Outer Space in Vienna in August 1968 and expressed no reservations in extensive discussion of earth resource surveys; and the United Nations has unanimously affirmed several measures to facilitate information and participation in this field by member states.
9. A. W. Frutkin, *International Cooperation in Space* (Prentice-Hall, Englewood Cliffs, N.J., 1965), chap. 3, pp. 85–131.
10. See *Congr. Rec.*, pp. S14028–29. The full text of the material cited by Senator Pastore on 10 November 1969 appears in a staff paper, "U.S./U.S.S.R. Cooperation in Space Research," prepared by the Office of International Affairs, NASA. The paper is periodically updated to record continuing U.S. initiatives. The latest amendment is dated 6 March 1970.
11. For an elaboration of these current efforts to increase foreign participation and a more detailed report on many elements of this article, see testimony by the administrator of NASA, Thomas O. Paine, in *Hearings before the Committee on Aeronautical and Space Sciences, United States Senate, Ninety-first Congress, Second Session, on S. 3374* (11 March 1970), *Part 3: International Space Cooperation.*

Cyclic Adenosine Monophosphate in Bacteria

In many bacteria the synthesis of inducible enzymes requires this cyclic nucleotide.

Ira Pastan and Robert Perlman

Escherichia coli contains the genetic information for the synthesis of enzymes needed to utilize many substances as sources of carbon and energy (*1*). Ordinarily, however, this genetic information is not expressed; the organisms only make the enzymes required for the utilization of a particular compound when that compound (or an analog) is present in the medium (*2*). For example, two proteins are required for the utilization of lactose: a galactoside permease, which permits the entry of lactose into the cell, and β-galactosidase, which catalyzes the hydrolysis of lactose to glucose and galactose. (A third protein, thiogalactoside transacetylase, is synthesized coordinately with the other two; its role in lactose metabolism is unknown.) The addition of lactose, or a nonmetabolizable lactose analog such as isopropylthio-β-D-galactoside (IPTG), to a culture of *E. coli* induces the synthesis of large amounts of these three proteins; in the absence of an inducer they are present in only very small amounts (*2*). Similarly, other potential carbon sources induce the enzymes required for their metabolism. The mechanism by which β-galactosides induce β-galactosidase synthesis has recently been reviewed (*3*).

The presence or absence of inducer is not the only factor which regulates the synthesis of inducible enzymes. Even in the presence of lactose or IPTG, the differential rate of β-galactosidase synthesis (the rate of enzyme synthesis divided by the rate of total protein synthesis) can vary greatly, depending on the medium in which the cells are growing. The differential rate is high in cultures where succinate is a carbon source, in which growth is slow, and low in cultures with carbon sources such as glucose, which permits rapid growth. The repression of inducible enzyme synthesis by glucose has been known for many years and was originally called the "glucose effect" (*4*). More recently, other carbon sources have been found to cause a similar repression, and so new names, such as "metabolic repression" (*5*) or "catabolite repression" (*6*), have been used to describe the phenomenon.

In 1965, Makman and Sutherland reported that *E. coli* contained the cyclic nucleotide adenosine 3′,5′-monophosphate (cyclic AMP) and that glucose lowered the concentration of cyclic AMP in these organisms (*7*). Cyclic AMP has an important regulatory role in animal cells (*8*), and it seemed possible that it had an equally important regulatory role in bacteria. We postulated that the repression of enzyme synthesis by glucose and other carbon sources might be due to the lowering of the concentration of cyclic AMP by these compounds. The addition of cyclic AMP to cultures in which β-galactosidase synthesis was repressed by glucose or other carbohydrates largely overcame this repression (*9–11*) and increased enzyme synthesis toward the level found in cells grown with succinate (*12, 13*) (Table 1). The effect was specific for cyclic AMP. Other adenine nucleotides, such as adenosine triphosphate (ATP), adenosine diphosphate (ADP), 5′-AMP, and 3′-AMP, and analogs of cyclic AMP, including 2′-deoxy cyclic AMP, N^6,$O^{2'}$-dibutyryl cyclic AMP, N^6-monobutyryl cyclic AMP, and cyclic guanosine 3′,5′-monophosphate were ineffective.

A second effect of glucose is observed when glucose is added to cultures grown on a poorer energy source, such as succinate or glycerol, and induced to make β-galactosidase. After the addition of glucose, there is a transient period of complete or almost complete repression of β-galactosidase synthesis. The duration of this "transient repression" is variable, but is often on the order of 20 to 30 minutes (*14–16*). After the period of transient repression, β-galactosidase synthesis resumes but now at the lower differential rate characteristic of cultures grown on glucose. Cyclic AMP prevents both types of repression (Fig. 1). Therefore, both forms of repression appear to be due to lowered cyclic AMP concentrations; apparently, the cyclic AMP concentration is lower during transient repression.

Glucose represses the synthesis of a number of inducible enzymes and trans-

Dr. Pastan is chief, Molecular Biology Section, Endocrinology Branch, National Cancer Institute, and Dr. Perlman is senior investigator, Diabetes Section, Clinical Endocrinology Branch, National Institute of Arthritis and Metabolic Diseases, National Institutes of Health, Bethesda, Maryland 20014.