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After the Moon, the Earth!

Walter Orr Roberts

Shortly after the turn of the 17th century, Galileo Galilei gazed with wonder upon lunar craters, which were revealed for the first time by a new invention, the telescope. It was, he said, a "most beautiful and pleasurable sight." More important, however, was the fact that Galileo's observations opened a whole new era of observational astronomy. The science, philosophy, and poetry of the subsequent centuries show the imprint of man's audacity in discovery about the heavens.

Now, 360 years after Galileo's first overwhelming view of the rugged terrain of the moon, four men have walked on those very mountains of the moon. Today you and I can look for ourselves at the strange, gray, porous-looking rocks the astronauts brought back from the moon. It was an exciting moment for me, a few weeks ago, when I visited the public museum at NASA, Houston, to look from bifocal proximity at these drab rocks and to ponder about the scintillating reflections that came, apparently, from irregular glassy lumps in small holes at many points of the rock surface.

The Goal of Reaching Another World

Less than a decade ago, on 25 May 1961, President John F. Kennedy made the moon landing a national goal. The United States, he said, "should commit itself to achieving the goal, before this decade is out, of landing a man on the moon and returning him safely to the earth." I must confess that I was afraid that the President had asked us to accomplish the impossible. The task demanded technological attainments of unprecedented complexity and difficulty. It required supreme skills in a field of engineering where we had much yet to learn.

But the goal has been attained, not once, but twice. Its accomplishment is not only a triumph of science and technology but also one of the truly great adventures of mankind.

To visit other worlds has been one of the long-unfulfilled dreams of mankind. Only a few years after Galileo's first drawings of lunar terrain, the astronomer Johannes Kepler, discoverer of the laws that govern planetary motions, wrote a fascinating and poetic science-fiction story, *Somnium*, in which earthlings were transported to the moon over the bridge of shadows that briefly spans the quarter-million miles to the moon during a lunar eclipse. There they met strange, tough-hided creatures. Many other writers followed Kepler's lead, creating fanciful tales of space adventure.

Cyrano de Bergerac wrote in 1656, with irrepressible but unscientific exuberance, of a marvelous jet-propelled spaceship in which he traveled to the moon and the sun. His contraption, scarcely less imaginative than Apollo 12, looked like a combination of a globe, an oversize filing cabinet, and a huge sail; it was propelled by jets of steam, and rose with the morning dew. On the moon, the prophet Elijah showed Cyrano how to use magnetic propulsion.

Then, as now, there were critics. Samuel Johnson was speaking of Cyrano, among others, when he wrote caustically, in *The Adventurer* for 10 April 1753, of ideas like space travel:

> A voyage to the Moon, however romantic and absurd the scheme may now appear since the properties of air have been better understood, seemed highly probable to many of the aspiring wits in the last century, who began to dote upon their glossy plumes and fluttered with impatience for the hour of their departure.

But the skeptics did not deter either the enthusiasm of the fiction writers or the efforts of the serious proponents of flight into free space. Jules Verne's prophetic *From the Earth to the Moon* had a great impact on world expectations for space travel.

The accelerating drive toward mastery of space brought to the scene men like Tsiolkovsky, Goddard, Oberth, von Karman, and von Braun. An instrument of war, the German V-2 rocket, made a giant stride, on 3 October 1942, by lifting off at 14 tons and flying its payload 50 miles into space. The threshold of the space age was first crossed, however, by the electrifying Sputnik I, a Soviet satellite of 184 pounds payload fired into earth-circling orbit on 4 October 1957.

I shall never forget that Friday evening. I had been present in Barcelona, the year before, at a planning meeting for the International Geophysical Year, and I had heard the chairman of the Soviet IGY Committee announce his country's preparations for launching a scientific satellite. But I was not prepared for the world-stunning impact of the event, when it occurred. I hurriedly rearranged some powerful radio receivers at our laboratory that evening, and then listened and tape-recorded the sounds of that first 20-megahertz space transmitter as it passed over the United States in the early evening of that first day.

When the Soviet Union launched Sputnik II, just a month later, with the dog Laika as passenger, the world was

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aware that we had entered a new age. Men in every country suddenly sensed the pace of modern scientific and technological advance. The fact that this marvelous feat of engineering had been achieved by the Soviet Union and not by the United States was noted everywhere, and it was a great blow to American self-confidence. The impact on world opinion and on domestic opinion was remarkable. Considering the magnitude of the event, however, I do not think the reaction surprising. Our self-esteem was not helped, in early December, when our country's first effort to orbit a man-made satellite, Vanguard I, ended in a gigantic explosion and fire.

The events had been preceded in our country by cutbacks in federal support of scientific research not unlike those occurring now. But the reaction to the setback in prestige went far deeper than simple restoration of the budget cuts. The Sputniks stirred an American self-assessment that affected everything from science to the priority ranking of national goals and domestic political attitudes. Even the very assumptions underlying our educational system came under grave questioning.

The effect of the Soviet achievements on our world image and our self-image persisted, even though Vanguard II and Vanguard III, launched but a few months later, achieved their aims. The U.S. Army's Explorer satellites of early 1958 were even more prominent and scientifically successful. I well remember, for example, the IGY Special Committee meeting in Moscow in the summer of 1958, where Homer Newell presented exciting new results about the trapped radiation belts, relayed by cable from James A. Van Allen, who had discovered the belts and mapped out their main features from Explorer-series satellites.

The months that followed the first Sputniks saw the creation of NASA, and the origins of America's great push into space science under distinguished civilian leadership, and in full view of the world. The achievement of President Kennedy's goal, last July, with the first moonwalk, was an incredible event. It was not only the realization of a national objective but the fulfillment of man's agelong yearning to visit another world. It is estimated that the July moon venture was seen or heard, live or in replay, by one-fourth of all the people of the earth! I watched with a small group before a flickery TV in a room in the Sejong Hotel in Seoul, Korea. Outside, the normally bustling traffic of the street was nearly halted, as if during curfew. Later in the day everyone—university professors, policemen, elevator girls, waiters, taxi drivers, shopkeepers, and even pedestrians on the street—hailed the event and congratulated the Americans.

It is interesting, from today's perspective, to compare actual events with the expectations of only a few years before Sputnik I. For example, the noted Russian scientist V. V. Dobronravov, who then headed the Interplanetary Navigation Committee of the Soviet Air Force Aero Club, in July 1954 wrote a timetable of expected space accomplishments. It went like this: 1965, unmanned earth-orbiting satellite, low orbit; 1975, three-man, earth-orbiting space ship; 1980, manned trip to moon orbit, no landing; 2000, manned rock-collecting field trip to the moon. Dobronravov was not a poorly informed prognosticator; the pace and priority of the Soviet and American efforts have simply exceeded earlier expectations. Moreover, the gigantic group efforts applied to the problem by both nations have demonstrated the almost irresistible power of large group efforts to achieve earnestly sought goals that are technologically feasible. Dobronravov's timetable was more a political-economic prediction than a technological-feasibility forecast, and it was grossly conservative.

NASA's policy of conducting all of its flight operations in full view of the world brought admiration at home and abroad. By so doing, we demonstrated that we were not afraid to show our failures as well as our successes. The world was watching at our launches, for better or worse. The record of safety and success is fantastic, in spite of the tragedy of "the fire" which cost the lives of three of our astronauts, including Edward White, who talked to the AAAS of his orbital space walk at our Berkeley meeting in 1965. The United States can now look with pride upon its space program. Its success has made a firm imprint on the thinking of people in every part of the earth.

Many men and animals, Soviet and American, have orbited in space to bring knowledge of the physiological and psychological effects of sustained weightlessness and other aspects of space flight. Unmanned probes have brought new details of the planets Venus and Mars. Soon we shall have the answer to the ancient riddle of whether there is earthlike life on Mars, or indeed any recognizable life at all.

Waste products of Soviet and American launches—hundreds of pieces of man-made space debris—wander in earth-circling or deep space orbits, or lie inert on the lunar surface. Astronauts Conrad and Bean revisited our unmanned Surveyor lunar laboratory in their Apollo 12 pinpoint landing and brought back fragments of the craft for analysis of the deterioration wrought by more than 2½ years in space. The moon's Sea of Tranquillity and Ocean of Storms bear crisscrossed footprints of earthmen that will be eradicated, in all likelihood, only after millions of years of cosmic particle bombardment. Overboots, film cassettes, used packages, tools, backpacks, cameras, and other discarded items dot the lunar landing sites. Among them are deployed seismographs, corner reflectors, and other still-operating experiments sending data to the earth. And there are, too, plaques and mementos honoring Soviet and American spacemen who died seeking to learn the mysteries of the cosmos. In this exotic place these artifacts of man will probably outlast the civilization of earth itself.

Space technology has, alas, also vastly enlarged the arsenals of the United States and the U.S.S.R., bringing to reality hitherto fanciful modes of military surveillance, communications, and weaponry. No point on the earth is more than minutes from the possibility of atomic attack by orbital or ballistic weapons carriers. The major powers stockpile ever more powerful and more deceptive ballistic missiles, antiballistic missiles, and anti-antiballistic missiles. The end of the spiral is not in sight. It is quite certain that, even if a civilian space program had not emerged, weapons would be poised for ballistic or space orbit. The V-2 demonstrated, if anyone needed such proofs, that man's ingenuity can be turned as well to instruments of war as to tools of peace.

In the years between Sputnik I and Apollo 12 many scientific or practically useful advances have occurred as a direct result of space research, and many nations besides the Soviet Union and our country have participated in these developments. Unmanned probes have explored the solar wind, have monitored the sun in hitherto inaccessible wavelength ranges, have registered the interplanetary magnetic field deep in space, have discovered the magnetosphere of the earth and its trailing tail, and have uncovered totally unexpected properties of the trapped radiation of the Van Allen belts. The science of cosmic-terrestrial relations has been profoundly altered by these discoveries. Earth-synchronous and low-orbit satellites have given us a new and highly useful view of earth weather, and have entered into routine global service for weather forecasting. Indirect probing of atmospheric temperatures has given astonishingly successful results, promising major advances in global weather measurement. Communications satellites are being used with increasing reliability and economy for a rapidly growing range of applications. Satellites are also finding significant uses in astronomy, geology, hydrology, forestry, oceanography, navigation, geodesy, and aeronomy.

Each new flight to space brings fascinating new mysteries to be unraveled. Apollo 11 revealed the glassy lumps in the small craters, perhaps evidence of a prehistoric superflare of the sun, and gave us samples of the strange, colorful, tiny glass spheres abundant in the lunar dust. The seismograph left by Apollo 12 revealed, when the spent lunar escape module was crashed back against the moon's surface, a weird, long-lasting, one-cycle-per-second oscillation that first rose slowly to a crescendo, then declined, remaining detectable for 50 minutes. These and the many more mysteries of this strange, dead companion-world of the earth will stimulate new experiments and new discoveries, some perhaps with direct significance for our world.

There can be no doubt that President Kennedy's goal has brought us great returns, both tangible and of the spirit. Before we have completed the seven additional Apollo lunar explorations that are scheduled through 1973, we will have placed still more sophisticated scientific experiments on the moon, and we will have obtained field data from a wide range of additional locations on the moon.

With this great goal nearing realization, it is necessary, now, to look to the next steps in space. What are the alternatives before us? Shall we seek to send a man to Mars, as some advocate? If we do, should we set a timetable for reaching the goal? Shall we abandon our hard-earned skills in space and turn our scientific-technological drives toward other kinds of goals entirely? Hard choices face us. We have grave problems in the international realm, of which the Vietnam war is but one. Can any nation be secure in a world that is part rich and part poor? Can the earth's population spiral ever higher without ominous consequences for all? At home, pollution of the environment, decay in the core city, chaos in the air traffic lanes, disenchantment of the young with our values and our choices —these and other problems crowd upon us, and make demands on our resources. Where does space research stand among man's needs in these areas?

I am not able to answer these hard questions directly. However, in the remainder of this address I want to express my personal views about the best next steps in space for our nation and the world. I am aware, of course, that thoughtful men have expressed quite different conclusions on these matters, and that I cannot hope for immediate or universal acceptance of my position. But I do hope that there will be a sustained and thoughful national debate before our decisions are irrevocably sealed.

After the Moon

I believe that the time has come, at this moment of great achievement for the United States, for us to take a bold new step in space. I propose that this nation call upon the Soviet Union to join hands in space, with a jointly conducted, earth-oriented space program that will put the new-found Soviet and American skills in space to work for the direct benefit of man, and with a maximum of international cooperation. There are many effective ways in which this can be done, with vast potential returns both in the short run and in the longer term.

By aiming the main thrust of our post-Apollo space efforts toward beneficial terrestrial applications, we can serve the tangible interests of people in all corners of the globe, and we can also greatly advance international cooperation and international understanding. There are extraordinary opportunities, in a properly conceived space program, for multinational planning and execution of specific experiments and investigations oriented toward the peaceful uses of outer space, both for pure science and for direct earth-oriented applications. By working jointly with the Soviet Union we can make the effort a matter of joint prestige—a matter of man against the unknown, rather than of Americans versus Soviets.

There is, moreover, a magic in the perspective from space that makes our planet appear as the hospitable, good earth that it really is for man. Nearly all of those who have been in space have a new view of earth. From lunar orbit, the earth is home—not Houston, or the United States, or North America, but "the good earth," as the crew of Apollo 8 expressed it in greeting us from the first lunar orbit on Christmas day just a year ago. What better step, at this time, than to internationalize our efforts in space, and to direct them largely toward improving the abode of man and achieving peaceful relationships among nations.

Yuri Gagarin, the Soviet cosmonaut who lost his life in that nation's space effort, spoke articulately to this point in May 1966:

> It is very important, in my opinion, to enlarge international cooperation for mastery and use of cosmic space, so that each flight of man into the cosmos, each launching of stations and of scientific laboratories in space will serve all mankind in the name of life and of peace.

If man's yearning for the secrets of other worlds is great, his yearning for a peaceful and plentiful world is even greater. With imagination, we could just perhaps make the space program of the future a major contributor to the realization of these added dreams of all mankind.

Let me turn to some specific suggestions. In my view, there would be great benefit to our nation and to the world if we were immediately to announce our intent to initiate, as our major post-Apollo thrust in space, a series of joint Soviet-American space programs also open to other nations as collaborators. These efforts could begin almost at once, with the space research areas where there are needs for satellite launches by both countries and where there is some degree of parity between the state of advancement of the present operations of the two countries. Let me give three specific examples of areas in which I believe we could organize joint programs in the decades to come.

1) *Applications satellites.* Remote sensing in visible and infrared wavelengths affords a number of areas where there would be virtue in the creation of coordinated Soviet-Ameri-

can experimental programs, with assignment of space on vehicles to experimenters of both countries. This would permit intercalibration and intercomparison of the different sensors and techniques on identical information fields.

There would, of course, be some problems. I am sure that both countries would face difficulties over the "interface" between classified and unclassified work; these could certainly be solved. Questions concerning compatibility of readout systems, telemetry resolution, and the like would also arise. It seems to me highly probable that it would not take long to achieve the goals in spite of the problems.

The first areas for joint work would probably be those where substantial cooperation has already been the rule, such as in remote sensing of the atmosphere's temperatures for meteorological purposes. Certain areas of solar physics and of interplanetary particle and magnetic field probing hold similar promise of mutual benefits from joint work, and have a similar history of close international cooperation.

I do not propose, here, to describe the many important areas of earth-oriented satellite applications that offer promise of advances in pure research and in benefits of practical importance to man. All of them are areas suitable for a joint space program. Some have greater promise and practicality than others. A detailed study (*1*) has recently been concluded and published by the U.S. National Academy of Sciences, with attention given to the probable practical uses to which earth-oriented satellites can be directed in coming years, and with recommendations for next steps. The fields embraced include such areas as meteorology, forestry and agriculture, geology, oceanography, communications, navigation and traffic control, economic analysis, geodesy, and cartography. The sights were perhaps not set high enough in this study, but it would be a good beginning from which to approach the Soviets.

The interest in such applications is no less intense in the Soviet Union than it is here. Participation in discussion of earth-oriented satellite applications at the International Astronautical Federation, for example, has been enthusiastic, and detailed. Strong Soviet enthusiasm is found in areas relating to agriculture and climatology. I have also heard Soviet scientists discuss with great optimism the possibilities for manned orbital laboratories staffed with teams skilled in earth-resource research, from agriculture to mineralogy to air conservation, and I discuss the prospects for a cooperative space laboratory below.

2) *Joint U.S.–Soviet Venus and Mars exploration programs.* In planetary exploration programs, Soviet-American cooperation might be especially fruitful. I maintain that the thrust in Mars exploration should not be "a man on Mars," even if no date is set for the landing. In my view the thrust should be a solely scientific exploration, in which the best and the most economical means of achieving the desired scientific aims are chosen. This would, in all probability, rule out serious effort, at least now, to carry out a 2-year manned Mars landing, just as NASA has tentatively worked out mission details. The fearful jump in difficulty that a manned Mars landing entails, as compared to a manned moon landing, would bring manned planetary flight costs to levels that I hope appear prohibitive to others, as they do to me.

On the other hand, a joint Soviet and American program of scientific exploration, while not directly earth-oriented, seems fully justified at this juncture in history—among other reasons, as a means of satisfying man's curiosity about the universe. But it must not receive the lion's share of the space manpower and dollars, or rubles.

There is also great merit, in planetary science programs, in bringing in other international participants. In many instances mutual benefits could be attained simply by comparing plans for, and coordinating launches of, Soviet and American rockets destined for Venus or Mars, with each nation choosing its own collaborators. The present work of the international body COSPAR (Committee on Space Research) leans this way already, but does not go far enough. If our space program were specifically vectored toward cooperative space research, and if the Soviet Union were similarly oriented, the work of COSPAR would "graduate" to a far higher level of significance.

The accidental coincidence of Soviet and American Venus probes a year or so ago permitted a considerably better understanding of the temperature structure of that planet's atmosphere than would otherwise have resulted. Such benefits should occur by design, and not by accident. The Soviets' strength in the development of advanced, unmanned planetary probes will probably make this area of cooperation attractive to them, because they will be in a position of essential equality from the outset.

3) *A joint manned space laboratory.* One of the high-priority future items for space is, in my view, a manned space station, with earth-oriented research instrumentation and personnel. I can visualize a not-distant future time when such space stations will form an integral part of world monitoring networks, with teams of skilled observers studying hurricanes, tropical ocean-atmosphere energy transformations, ocean current flow patterns for fish-migration analysis, air pollution drift, and spread of insect pests and plant diseases, assessing water reserves in the world's watersheds, and making a host of other terrestrial studies.

The world would benefit from priority efforts toward development of such space stations, served by space shuttles and space tugs and manned for considerable periods by trained crews. I believe that such stations should be developed under international auspices, and should be manned cooperatively by individuals from a variety of nations, or by international public servants. The United States could make a great contribution to world understanding by announcing, at this time, a program to internationalize our efforts to build, man, and operate research and operations stations in space. It would be possible to put international teams into the stations that will follow directly after the prototype U.S. space station now scheduled for launch in 1972. It can be done in Antarctica; why not in space?

There are, of course, problems that come about from the military uses of space that neither the U.S.S.R. nor the United States will want to compromise by internationalizing all space knowledge. But the separation that already exists between NASA and the military space program should make this a minimal obstacle on our side. I believe that there is no better time than now to try. Moreover, such an effort might trigger better progress in arms limitation and in open-skies policies for the world. From a spaceship it is hard to see the logic of political boundaries. A new concept of sovereignty of nations might turn out to be the most important ultimate product of joint space stations.

International Centers for the Peaceful Uses of Space

Until more nations of the world can participate actively in the benefits from space research, the true potential of our new-found space skills will be at least partially wasted. I believe, therefore, that it is appropriate, as a part of our plans for a post-Apollo space program, to seriously consider creating, in developing regions of the world, new kinds of international space research centers oriented toward the exploitation of space science and technology for the practical benefit of local, but broad, geographical regions. A center for Africa, for example, would make good sense. Similarly, one for Latin America.

The focus of such centers would be on the research and development that would lead to improvements in exploration for mineral resources, control of agricultural pests, improvement of crops, effective use of forest resources, development of marine resources, prediction of weather and climate—all through the use of space tools and techniques, imaginatively coupled to earth-based research and development.

The fields of promise for such centers embrace, for example, geology, weather, forestry, agriculture, fisheries, computer science, environmental pollution control, and communications (including communications in the areas of education, medicine, entertainment, and commerce).

A center dedicated to this purpose, for example, might resemble, in some important ways, an international version of the laboratory with which I am affiliated, the National Center for Atmospheric Research, at Boulder, Colorado. It would have a strong component of pure science, but there would also be skilled engineers and technicians on its staff, and it would carry out applied research and development as well. Its research facilities should be of high quality and power. And it should fulfill, as well, an important educational and training function, though it should not be a university.

In such a center there should be various groups and divisions dedicated to problem-solving related to specifically chosen social and economic needs of the continent or region in question. There should also be pure research activity in the fields most relevant to the specific problems. For example, there would need to be, for exploitation of space-sensing of oil resources, geologists familiar with the principles of petroleum geology and also knowledgeable about the geology of the regions involved. Obviously, there would be need for a good deal of training in the space-based techniques, and one might also expect that the center would become a focus of new discoveries regarding ways to instrument and use satellites for such purposes. In particular, the center would be a direct readout point for the remote-sensor data from space satellites programmed to provide the fundamental inputs for regional research.

Each center would need to be under the direction of a highly skilled scientist or engineer who was dedicated to its goals and who was in close communication with the satellite-development and launching agencies abroad. The staffing of such centers would probably have to involve a mix of senior scientists from highly developed countries and from the local region embraced by the center.

A large fraction of the staff of such a center would obviously have to be visitors, but there would have to be very outstanding resource people on hand permanently. Especially is this so in regard to the computer facility that would be needed at such a center.

The creation of appropriate management and financing might be a ticklish business, as would be some of the necessary agreements regarding on-the-ground backup for the space-based sensing. Another difficult area would be the matter of "user taxes" or other questions that would arise when major resource development in a particular country derived, at least in part, from the work of a center. There would be jockeying about the location of the center. Nonetheless, these problems can be solved, I am sure.

I see no reason why the United States and the Soviet Union could not, cooperatively, provide systematic help to such centers. This help could consist of the design and launch of satellites for the resource programs, as well as the provision of compatible readout capabilities. Most important of all, however, would be scientific and technical consultation. If the prosperity and effective operation of such international centers for the peaceful uses of space were a significant aspect of our space program, we could provide the solid kind of support that would greatly enhance the probability of their success.

The Global Atmospheric Research Program

The most interesting and important earth-oriented space program of the future, save perhaps for the communications program, is, to my mind, one in the domain of atmospheric research and applications. I should say, in passing, that the atmosphere-ocean envelope of earth and certain aspects of the solid earth must be regarded as a single geophysical entity. Thus, physical oceanography and atmospheric dynamics are both essential components of atmospheric research, and the sensing tools deployed for the atmospheric research programs must measure the oceans as well as the atmosphere.

In spite of the amount of domestic emphasis that has been given the Global Atmospheric Research Program, it has not achieved its merited degree of public or official visibility. It should, in my view, be elevated to the status of a major objective of the U.S. space program for the decade ahead. Again, the world cooperative aspects should be emphasized. Internationally, planning for the Global Atmospheric Research Program is moving fast, and there is remarkable interest and enthusiasm. But the United States should do far more to sustain the momentum and priority of this critically important program.

The Global Atmospheric Research Program merits priority attention for the following reasons:

1) Its underlying aim is the benefit of all mankind through improved knowledge of weather and climate.

2) It is made-to-order for international cooperation, and in fact cannot come about without extensive cooperation that will involve many of the underdeveloped countries in the use of simple tools and techniques to give regional data for a global network.

3) It excites the interest of the general public as do few scientific or technological questions—especially since it includes work on many important aspects of weather and climate modification, both deliberate and inadvertent.

4) Space technologies are essential to its success, though it also makes strong demands upon conventional meteorology.

5) Detailed studies have been carried far enough so that we know fairly well its probable dimensions, costs, and products. There are enough gambles to make it exciting.

6) It has its roots in earlier U.N. resolutions introduced by the United States for the peaceful uses of outer space.

7) The Congress, by resolution, has indicated its interest in it as a national goal.

For these reasons, I urge that it be made a vital element of this nation's post-Apollo efforts in space.

Through Space, a Better World

The greatest thrill I can imagine for myself is to stand on the moon's surface and to look back from the harshness of the lunar landscape to the luminous hospitable earth. From that vantage point, I believe, I could view the earth in its oneness. There I could better understand that indeed all mankind properly shares in the pride of attaining a lunar landing. After all, it is science and engineering, the common heritage of all mankind, that made it possible! All nations and races have contributed to the unbroken threads of knowledge that comprise science.

From space, the earth must indeed appear a rare and beautiful place in the vastness of the universe. I sometimes gain this sense of the emptiness and scale of the cosmos when I fly my plane over the lightless reaches of western Nevada on a dark, clear night and see the Galaxy stretched out overhead.

The past steps in space have required extraordinary bravery and emotional stability on the part of the men of our space program, who understood, as the public only vaguely does, the hazards of the task. To take the next great step in space will require no less skill and knowledge, equally steadfast courage, and a parallel sense for innovation. The next step in space must be directed toward the earth. We must turn our newly discovered skills toward the construction of world systems that make the planet earth even better than it is now for its burgeoning numbers of people. We must invent new world-technologies. We must commit the resources of space science, directly and indirectly, to the achievement of an optimum balance of man and nature on this magnificent but imperiled planet.

Reference

1. *Useful Applications of Earth-Oriented Satellites* (National Academy of Sciences, Washington, D.C., 1969).

Meteorology and the Supersonic Transport

Research in stratospheric meteorology has significance for future operations of the supersonic transport.

Frederick G. Finger and Raymond M. McInturff

The proposed supersonic transport (SST) should bring about great changes in commercial aviation—changes at least as radical as those which resulted from the inauguration of subsonic jet aircraft. Cruising speeds of the initial supersonic transports will be two to three times faster (up to about Mach 2.7) than those of today's airliners, and ceilings for needed meteorological data will be nearly twice as high (up to about 20 kilometers). Two different designs of SST, the Anglo-French Concorde and the Russian TU-144, are currently being flight-tested; the U.S. version is in the design stage.

Since meteorological support to commercial aviation is necessarily tailored to the characteristic flight levels of the various types of aircraft in use, information on stratospheric levels (see Fig. 1 for accepted definitions of atmospheric layers between 0 and 22 kilometers), will, for the first time, be needed for routine civil-aviation operations. At present, data from heights up to about 12 kilometers provide the basis for all meteorological operations—public forecasts, aviation forecasts, and so on. These data are obtained from the vast network of surface observational sites and the more than 800 upper-air stations, most of which regularly take balloon-borne radiosonde observations of temperature, wind, and humidity twice daily (*1*).

Only recently have meteorologists begun to receive sufficient stratospheric data, mostly from the Northern Hemisphere, to conduct intensive research for these high altitudes. Even though current operations do not require data above 12 kilometers, there has been a concerted effort on the part of all nations to provide meteorological data to the greatest possible heights. This effort is being aided by technological advances, most notably in balloon fabrication. The greatest progress has taken place in anticipation of special scientific periods, such as the International Geophysical Year, 1957–58 (*2*) and the International Years of the Quiet Sun, 1964–65 (*3*).

The improvements in the upper-air observing network have had an obvious effect, but stratospheric data are still sparse and relatively inaccurate as compared with tropospheric data. For example, less than half of the total number of stations supply data above 16 kilometers for any given observational time. Moreover, data coverage is far less complete in the Southern Hemisphere than in the Northern. Despite the paucity of measurements and the perhaps more serious problem of inaccuracies within the data that are available, our knowledge of the higher atmosphere is rapidly increasing.

In this article we review the significant atmospheric phenomena that may affect either the safety in flight, or the economics, of the SST aircraft. Reference is made to the general nature of the meteorological support that will be required for operations. A prominent

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