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On the Future of Space Science and Applications

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Introduction

The scheme of my talk on the future of space science and applications is as follows:

First, a brief introduction on matters of perspective.

Second, an overview of the present status of space science and applications.

Third, a prospectus for future activities, an admittedly perilous undertaking but one founded on my active and continuing participation in the now some 33 years of space flight and on thoughtful consideration of its achievements and promise.

My talk contains elements of subjectivity and is therefore contentious. I recognize this and hope that my views will enliven the symposium.

Recently I have read David DeVorkin's book entitled "Race to the Stratosphere—Manned Scientific Ballooning in America". The author's point of departure is the 1931 balloon flight of the Belgian aeronaut Auguste Piccard to an altitude of nearly 16 kilometers. This flight generated widespread public interest both in Europe and elsewhere and was hailed as opening up a vast new frontier of human adventure and exploration. The sheer romance and public visibility of high altitude ballooning were Piccard's central motivations. But he felt it necessary to exalt his aspirations by wrapping them in the cloak of scientific objectives. His own attempts to make cosmic ray observations were, however, severely compromised by his necessary preoccupation with his life support system and the mechanics of the flight. As a result, his observations were much inferior to the previous and contemporaneous observations of the German physicist Erich Regener who relied on automated equipment carried by unmanned balloons to greater altitudes and at much less cost. Piccard resolutely ignored these facts and continued to rationalize his aspirations by a variety of specious assertions on the importance of hands-on operation of scientific equipment during its flight on balloons. Piccard's point of view appealed to the general public and therefore gained the support of some industrial organizations and even a few scientists.

The pre-World War II culmination of manned scientific ballooning was the November 1935 flight to an altitude of 22 kilometers by Albert Stevens and Orvil Anderson. Following the War, there was a brief and troubled revival of this activity and in May 1961, Malcolm Ross and Victor Prather reached an altitude of 34.7 kilometers with an array of automated instruments for measuring atmospheric properties. This Stratolab flight ended the epoch of flying human crews on high altitude balloons.

It had been evident already for many years that automated equipment on unmanned balloons provided a greatly superior technique for scientific measurements within the atmosphere.

At the present time, scores of unmanned balloon flights are made each year for scientific purposes but manned ballooning survives only as an adventurous sport.

Much of the history of scientific ballooning falls within my direct personal knowledge as does the entire history of space flight. On many occasions I have compared the two histories. This theme of historical parallelism is developed by DeVorkin in a richly detailed and persuasive way.

The apparent conclusions are (a) that the conduct of scientific and applicational missions in space by human crews is already an obsolete technique and (b) that justification for future manned space missions must rest on other considerations-those of a general cultural nature such as inspiration, high adventure, human recordsetting, and the like. It would be refreshing to hear a prominent political leader make such statements, assess the motives for manned space flights in the context of their significance and costs and not obfuscate the matter with a plethora of false analogies and unsupported claims of practical objectives.

Any attempt to visualize the future of space science and applications must consider the relative roles of manned and unmanned spacecraft. The route of easy virtue is to declare in favor of a "balanced" program. But such a simple declaration is, of course, meaningless. It becomes meaningful and discussable only if one specifies a quantitative ratio of the respective efforts and explains the rational basis for such a ratio. Otherwise, advocacy of a "balanced" program is what my father would have called a platitudinous pomposity.

The issue of balance is a fundamental one. It will not go away. It can not be waved aside. It is already an acute issue in the U.S. and the U.S.S.R. and is prospectively so in other countries.

I will now offer my own attempt to assess it.

On the Nature of Space Science

In a previous paper I have written as follows:

"Space science is not a professional discipline in the usual sense of that term as exemplified by the traditional terms astronomy, geology, physics, chemistry, and biology. Rather, it is a loosely defined mixture of all of these fields plus an exotic and expensive operational style. The distinctive features of space science are the use of rocket vehicles for propelling scientific equipment through and beyond the appreciable atmosphere of the Earth; the rigorous mechanical, electrical, and thermal requirements on such equipment; and (usually) the remote control of the equipment and the radio transmission of data from distant points in space to an investigator at a ground laboratory. Space science is primarily observational and interpretative; it is directed toward the investigation of natural conditions and natural phenomena. But it can be and sometimes is experimental in the sense that artificial conditions are created and the consequences observed. Most space science has been and will continue to be conducted by unmanned, automated, commandable spacecraft. But some is conducted by human flight crews performing direct hands-on manipulation of equipment. The latter mode of operation is of dubious efficacy and, in any case, will probably be the technique of choice only in specialized subfields involving preliminary laboratory-type experiments under free-fall and low-g conditions."

It is common to state that the space age began with the successful launching of the Soviet's Sputnik I in October 1957. This is a defensible statement but space science, as I have defined it, was anticipated by astronomical observations throughout recorded history. More specifically, observations through and above the appreciable atmosphere of the Earth by scientific equipment carried by rockets began in 1946 and continues actively at the present time—as exemplified by the important work at the high latitude Andøya Rocket Range in Norway.

A proper description of the scientific advances that have been achieved by space techniques is far too voluminous for a short talk. Many basic geophysical and astronomical discoveries are made each year and the total volume of original work is truly staggering. Let me list a few examples.

Knowledge of the composition, structure, and dynamics of the Earth's atmosphere and ionosphere has been greatly expanded and clarified. Such work is central to the theme of this symposium. Corresponding but less comprehensive studies of the atmospheres and ionospheres of seven other planets of the solar system have been conducted on planetary missions. The results of these planetary studies have intrinsic interest and add depth to our attempts to better understand the Earth system.

The full electromagnetic spectrum of solar emissions, from gamma rays to radio waves, has been observed as has the sporadic solar emission of energetic particles. A much improved understanding of the dynamics of the quiescent and disturbed Sun and the consequences at the Earth has been achieved. Of special interest is the solar coronal plasma (or solar wind) which flows outward through the solar system and has now been observed to radial distances of over 50 astronomical units by Pioneer 10. The influence of the solar wind on the physical properties of the planets has become an important feature of the broad subject called solar-planetary relationships.

Knowledge of distant astronomical objects and the interstellar medium has been extended greatly by spacebased observations in the gamma ray, x-ray, ultraviolet, and infrared regions of the spectrum and by improved angular resolution.

The Earth's magnetosphere has been studied in great detail and it has become the prototype for the magnetospheres of the other planets and for analogous plasma physical phenomena of pulsars and large astronomical systems.

Oceanography, geodesy, and geology have also profited importantly by spacebased techniques. Such advances undergird long term forecasts of the future of the Earth as a habitat for life.

Planetary and cometary exploration is perhaps the crown jewel of space science. It has produced dramatic advances in understanding the full nature of our solar system, of its many elements, of its rich variety of current phenomena, and its probable evolutionary history. Many current research papers discuss the detailed geology (albeit a semantic perversion of terminology) of the Moon, the planets Mercury, Venus, and Mars, and the planetary satellites of Mars, Jupiter, Saturn, Uranus and Neptune. The character of the rings of the outer planets and the solar wind's interaction with cometary gas and dust are also subjects of special interest. The spacecraft Pioneer 10 passed a heliocentric distance of 50 AU about three weeks ago and continues to be the most remote man-made object in the universe, still transmitting scientific data continuously. Pioneer 10, its companion spacecraft Pioneer 11, and the two later spacecraft Voyagers 1 and 2 are all on solar system escape trajectories. There is a reasonable hope that at least one of these four will continue to operate and transmit data as it passes from the heliosphere into the interstellar medium.

In the realm of biological science, the most significant findings have come from the Viking landers on Mars. Their remotely controlled assays of surface material revealed an essentially complete absence of any biological material. These findings do not conclusively preclude the presence of biological material elsewhere on Mars or on some other non-terrestrial body in the solar system but do make such a possibility much less likely.

I recognize that the foregoing survey of the current status of space science is quite incomplete but I believe that it provides representative examples and suggests the future nature of the subject.

Needless to add, nearly all of these and the many other advances is space science have been achieved by unmanned automated spacecraft, controlled and monitored by teams of scientists and engineers from the comfort of resourceful terrestrial laboratories.

In the company of many others I served on a panel of scientists who prepared a recent report entitled "Space Science in the Twenty-First Century—Imperatives for the Decades 1995 to 2015". The two-year study was conducted under the auspices of the U.S. National Academy of Sciences. Our report comprises one overview volume and six other volumes with the following subtitles:

(1) Fundamental Physics and Chemistry
(2) Astronomy and Astrophysics
(3) Life Sciences
(4) Mission to Planet Earth
(5) Planetary and Lunar Exploration
(6) Solar and Space Physics

These documents summarize the rich agenda of our aspirations for the future. Aside from studies of human physiology and psychology under prolonged free-fall (or weightless) conditions, very little need for manned space vehicles emerged.

Space science throughout the world is supported almost entirely by governments, i.e., by tax-playing citizens. A tough minded politician is therefore entitled to question the appropriateness of any proposed level of effort. As one congressman put it to me as a Pioneer 11 scientist: "Why is it urgent to measure the magnetic moment of Saturn during 1979? Why is this effort in the public interest? After all, the planet will still be there 100 years from now."

Such questions are easy to ask and difficult to answer.

One form of answer, of course, is to cite the long history of pure science in laying the foundations for innumerable technical developments and their contributions to human welfare and to further cite specific examples.

I have no difficulty in defending the intellectual quality of astronomical science, for example, but I would not like what I see in a mirror if I were to claim that knowledge of the magnetic moment of Saturn is of any immediate practical importance. Nor do I attempt to do so. In such matters, I think that our best move is to fall back on the general public perception of "worthwhileness". Worthwhileness is a collective judgment which is quantified by the political process as a kind of equilibrium between advocates and skeptics. So it is with space science.

It is well known that scientists have a virtually unlimited capacity for planning new programs. The challenges of space research are noteworthy for spawning expansive thinking. I have often remarked that I can think of a one-billion dollar space project before breakfast any day of the week, or a two-billion dollar project before breakfast on Sunday. This is easy to do. Yet we must not delude ourselves by what has been called a triumph of hope over experience in formulating our programs.

Space Applications

Space applications is a short term for the use of space flight technology in providing direct and tangible human benefits of a utilitarian nature. Such applications are sometimes called "spin-offs". But I personally deplore the use of this term, which implies that they are incidental and without conscious intent. On the contrary, space applications are the result of purposeful and highly competent effort directed toward clear needs.

In some cases, they are derived from fresh knowledge gained by space scientists but more usually they have a much broader scientific and technological base. Some have commercial potential. Others lie primarily in the realm of governmental services.

The most prominent of space applications is the use of satellite relays for rapid domestic and international telecommunications. This is the only application of space technology that has achieved true commercial status in the non-governmental market place. Communication satellites serve an immense variety of civilian and military purposes and are a pervasive element of modern civilization. Their use continues to grow but they now have formidable competition in high-traffic point-to-point communication by way of optical fiber cables, especially transoceanic ones.

Another prominent space application is represented by satellites for the continuous monitoring of the Earth's weather on a global basis and for monitoring solar emissions. Special applications of meteorological satellites in surveying the ozone content of the upper atmosphere and the distribution of other minor but important components of the atmosphere are of increasing importance in determining both natural and anthropogenic fluctuations and trends. Also research satellites are of vital importance in clarifying the dynamics of the atmosphere and ionosphere, matters which mix pure science and applications to human welfare.

Another major area is that called remote sensing, typified by Landsat and Spot satellites for the sophisticated, multi-spectral survey of the surface and near surface features of the Earth and its oceans on a global basis. Again, such satellites have both civilian and military purposes. There is significant commercial potential for their observations but most of them continue to fall in the broad area of governmental services and there is no reasonable expectation that this situation will change markedly in the near future.

Networks of satellites provide the basis for navigation on land, at sea, and in the air with unprecedented accuracy and also have important applications to geodesy and geology.

My roster of examples of space applications is, of course, incomplete but illustrative of modern developments. It is a matter of regret that their importance in everyday life is so little appreciated by the general public including the news media which, ironically, are increasingly dependent on them in their daily operations.

All important applications of space technology utilize unmanned, commandable spacecraft, most of which have useful lifetimes of many years. It is ludicrous to suggest that human crews in space have any significance in the field of space applications.

Concerning the Space Flight of Human Crews

I now turn to some remarks on the future role of human crews in space from the perspective of our collective experience over the past three decades. I will use the common term manned flight but do so with the full recognition of the roles of both men and women.

In common with millions of others, I shared in the vicarious thrill of the Apollo landings on the Moon, including especially the TV coverage of Neil Armstrong lumbering down the short ladder from the Apollo capsule and setting his heavy boots on the lunar surface. This was on 20 July 1969, now over twenty-one years ago.

However, since termination of the Apollo and Skylab programs in 1973, manned flight has not been essential to any important scientific or utilitarian purpose despite the fact that, in the United States, it has consumed over two-thirds of the resources of our civilian space program.

In January 1972, President Nixon announced his approval for the development of a space shuttle—a winged recoverable spacecraft capable of carrying a human crew and over 20,000 kilograms of cargo. At that time NASA declared that four such vehicles would, by the early 1980s, supplant all U.S. unmanned expendable launch vehicles and would make possible fifty flights per year at a cost of $250 per kilogram of payload delivered into low earth orbit. It was also estimated that the useful lifetime of each vehicle would be of the order of one-hundred flights. Such gross optimism bordered on fraudulence as was evident to some of us who testified against the realism and wisdom of such a development in a sequence of congressional committee hearings following the President's announcement.

As of 1990, it is evident to nearly every expert person that the shuttle program has been a limited technical success but a gross failure of policy. Worse yet, it has plagued the progress of space science and applications by its voracious demands on resources and its conspicuous failure to meet its declared objectives. Following the public trauma resulting from the Challenger disaster in January 1986, the U.S. Department of Defense was, at last, able to break away from the presidential mandate to rely exclusively on the shuttle for delivery of military payloads into space; and it resumed procurement of a family of well developed expendable vehicles. The commercial telecommunication industry has followed suit as has our National Oceanic and Atmospheric Administration. In striking contrast, NASA has persisted in its heavy reliance on the shuttle and has taken only reluctant steps to diversify its launching capability.

Presidents Reagan and Bush have further jeopardized the future of the true benefits of space exploration and exploitation by advocating massive new programs of manned flight, thus in effect ignoring both experience and common sense. In his State of the Union address on the 25th of January 1984 President Reagan spoke as follows:

"We can follow our dreams to distant stars, living and working in space for peaceful, economic and scientific gain. Tonight, I am directing NASA to develop a permanently manned space station and to do it within a decade . . . A space station will permit quantum leaps in our research in science, communications, and in metals and life-saving medicines which can be manufactured only in space."

He continued with remarks on the enormous potential for commerce in space. A year later he reiterated his enthusiasm for space as the "next frontier" and emphasized "man's permanent presence in space" and the bright prospects for manufacturing large quantities of medicines for curing disease and extraordinary crystals for revolutionizing electronics—all in the proposed space station.

It is always pleasant to hear a presidential endorsement of one's professional field but in this case practitioners, such as myself, were staggered by the excessive, if not misleading, expectations that such statements create among those who are ill-informed.

Indeed, the concepts of "man's permanent presence in space" and "man's occupation of the solar system" are slogans widely repeated as though they were divine revelations, immune to rational discussion.

Six years into President Reagan's promised decade, the space station is still on the drawing board, being repeatedly redesigned in response to inadequate support by the White House and the Congress; and its estimated cost has grown from a promised $8 billion to a more realistic $40 billion, a poignant example of the reality gap.

A 20 July 1989 public address by President Bush contained expansive rhetoric similar to that of his predecessor, including an endorsement of the space station development *and* of the objectives of establishing a permanently manned scientific station on the Moon and conducting a round trip manned mission to the distant planet Mars.

But to his credit, he cautiously refrained from near term support for the latter two undertakings and directed a study of their feasibility, costs, and time scales by the National Space Council, chaired by Vice President Quayle. The results of this study have not been made public, but knowledgeable persons have already estimated that execution of the Mars mission alone implies average annual expenditures of $25 billion over a period of two to three decades or a cumulative total of about $600 billion (1990 dollars), representing some 10 million man-years of human effort.

It can be and has been argued that the United States can afford expenditures of this magnitude for such lofty cultural goals and such high adventure. But I judge that typical taxpayers and their representatives in the Congress do not have a manned mission to Mars among their national priorities. Worse yet, such presidential rhetoric does a great disservice to the many worthy, much less costly, and readily achievable scientific and utilitarian objectives of a thoughtful program of space exploration with unmanned spacecraft. The latter objectives include environmental monitoring of the Earth on a global basis and important contributions to assuring the health and welfare of future generations of its human inhabitants.

Conclusions

I conclude by summarizing my principal points. As you will see, they are in the framework of U.S. policy but I venture the opinion that they are worthy of consideration by other nations as well:

- NASA and its associated contractors and grantees, despite despair following the Challenger accident, continue to have high competence and constitute a unique national asset.
- Apart from the flourishing telecommunication industry, the true "commercialization of space", free of essential governmental subsidy, is a wan hope and hence a wrong-headed basis for policy.
- A "balanced" program within NASA should provide about 50% of the total resources available to the agency (including launch services, tracking, data acquisition and analysis, etc.) for space science and useful applications including aeronautics, and about 50% for all other activities.
- For almost all scientific and utilitarian purposes a human crew in space is neither necessary or significantly useful and the shuttle is the most expensive and least robust of available launching techniques.
- The civil space program of the United States must return to *primary* reliance on unmanned launch vehicles, as the communications industry and the Department of Defense already have.
- Space science and applications programs (NASA and NOAA) must *not* be held hostage to the manned flight program (shuttle and/or space station) but should have quasi-independent authority to make coherent long range plans and to procure *appropriate* launch services (as part of their budgets).
- Improved understanding of the Earth's environment on a global scale should be made a substantial element of NASA's direct response to the public interest (perhaps analogous to that of the National Institutes of Health); but the program should be developed incrementally and should not be overrepresented as a panacea to the world's environmental distress.
- The space flight of human crews may well be a worthy cultural objective in its own right (high adventure under exotic circumstances, inspirational, prestigious) for a wealthy nation, but advocates should acknowledge the realistic risks and costs and should not bewilder the issue with false claims.
- The planned U.S./International space station is on a scale grossly incommensurate with its clearly identified usefulness (cf. MIR, Skylab).
- The Human Exploration Initiative of the present Administration (permantently manned station on the Moon and manned expedition to Mars) is on such a long time scale and such a high level of cost as to be incompatible with realistic expectations of public support. Emphasis on such objectives does the entire space program a disservice.
- International collaboration in space should be cultivated in a natural way, as in the past, but should *not* be driven by political objectives.