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ABSTRACT

Congressional hearings held on October 8-10, 1985, were meant to characterize the attributes of past successes of the United States' efforts in the space sciences, and to project the direction of future research in that area. This report prepared by the subcommittee on space science and application includes recommendations of expert panels on solar terrestrial science, earth and life sciences, planetary exploration, and astronomy and astrophysics. The major issues addressed in the document are: (1) scientific cooperation with the Soviet Union; (2) the need for a global view of the earth provided by space platforms; (3) the relationship among operational, research, and commercial programs; (4) the role of space science in education; (5) the adequacy of flight opportunities in the current space program; and (6) the future role of the space station in space science. (TW)

[COMMITTEE PRINT]

SPACE SCIENCE: PAST, PRESENT AND FUTURE

REPORT

PREPARED BY THE

SUBCOMMITTEE ON
SPACE SCIENCE AND APPLICATIONS

TRANSMITTED TO THE

COMMITTEE ON SCIENCE AND TECHNOLOGY
HOUSE OF REPRESENTATIVES

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**Serving on Committee on the Budget for 99th Congress.

LETTER OF TRANSMITTAL

HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE AND TECHNOLOGY,
Washington, DC, May 1986.

Hon. DON FUQUA,
Chairman, Committee on Science and Technology, U.S. House of Representatives, Washington, DC 20515.

DEAR MR. CHAIRMAN: I am submitting herewith a report on the future of the space sciences. This report is based on testimony received during three days of hearings in October, 1985 before the Space Science and Applications Subcommittee.

This topic is of great significance to the Committee in view of the immense practical applications and intellectual contributions NASA's investment in the space sciences has yielded. Our review is also timely inasmuch as major changes in the nature of our space program are now beginning to emerge. These changes include the utilization of a permanently manned space station, the commercialization of space technologies, the use of space platforms to address pressing environmental concerns, and the potential renewal of cooperative agreements with the Soviet Union.

I commend this report to your attention.

Sincerely,

BILL NELSON,
Chairman, Subcommittee on Space Science and Applications.

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REPORT
Space Science: Past, Present and Future

I. INTRODUCTION

When the Congress passed the National Aeronautics and Space Act of 1958 it made "the expansion of human knowledge of phenomena in the atmosphere and space" a specific objective of our Nation's space program. In so doing, it recognized the importance of scientific research to the full utilization of space for "peaceful purposes for the benefits of all mankind." The space and Earth sciences have clearly demonstrated a major contribution to society's well-being through past accomplishments. These accomplishments have not only yielded a bounty of practical applications that have improved our quality of life, but have also been a major influence on our perspective of our place in the universe.

In its 1983 review of the NASA Act, the House Committee on Science and Technology concluded that "a healthy space science program is essential to maintain continued strength and vitality of the space program and to derive therefrom social, scientific, and economic benefits. NASA should initiate enhancement in the space and Earth sciences, including pursuit of planetary exploration through a renewed commitment to exploration of the solar system, and expansion of human knowledge of the Earth and phenomena in the atmosphere and space..."[1]

Notwithstanding the conceptual and practical importance of NASA's space and Earth science program, this area makes up only a small fraction of NASA's overall budget. However, this small fraction supports a large proportion of U.S. basic research in these disciplines. Thus any adverse impacts on these budget items may have severe reverberations throughout the scientific community.

On October 8, 9, and 10, 1985, the Subcommittee on Space Science and Applications held hearings to review the space and Earth sciences. These hearings were meant to characterize the attributes of our past successes, and with this background, to project where we should be in the future and what direction our research should take to get us there.

In holding these hearings, the Subcommittee was cognizant of a very important transition in progress in the space and Earth sciences. In the past, our scientific endeavors were primarily directed toward studying space. We discovered a great deal about our near-Earth environment such as the Van Allen radiation belts. Now we have matured to the point that we see space as a place from which to study other things. We use space for meteorology, oceanography, biology, astronomy, and even to carry out research in medical sciences. As such, there has arisen an increasing demand for both an interdisciplinary and an applications focus in the space and Earth sciences. This represents a

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[1]Report, Review of National Aeronautics and Space Administration Act of 1958, as amended, 98th Congress, 2nd Session, September 1984

challenge to NASA that must be met not only through well-conceived program planning and resource allocation but also through a flexible organizational infrastructure.

In order to examine these issues, the Subcommittee received testimony from eminent space and Earth scientists both within and outside NASA. The witnesses were asked to provide a broad overview of the past major accomplishments in space and Earth sciences and their impact on society and to offer their views on the future of the space sciences.

II. SUMMARY OF WITNESS TESTIMONY

This section summarizes the testimony of witnesses in the order of their appearance.

OVERVIEW PANEL

Dr. Carl Sagan, Cornell University, Ithaca, New York

Dr. Sagan expressed his view that despite the enormous successes of the unmanned space program, the manned program has generally enjoyed greater support. He pointed out that the Apollo program, however, combined the various scientific and technological constituencies, providing a common purpose which justified the large expenditures.

Dr. Sagan proposed another such major program which embodied many of the successful attributes of the Apollo program. He outlined his concept for a joint manned exploration of Mars between the U.S. and the Soviet Union. Although the scientific benefits alone do not merit the enormous costs, he said, the additional symbol of U.S.-Soviet cooperation and interdependence would be a promising long term goal.

Dr. Sagan recommended that this major mission be preceeded by smaller scale cooperative projects such as the intercomparison of data from the Soviet Phobos mission with that of the U.S. Mars Observer mission and at some future time, a joint unmanned Mars sample return.

Dr. Noel Hinners, NASA Goddard Space Flight Center

Dr. Hinners presented a broad overview of the fundamental advantages of investments in the space sciences. He emphasized that a major achievement in such endeavors is one of educating and stimulating our youth. Future science missions, he suggested, may benefit educational objectives to an even greater degree through an extensive telescience network in which student involvement in experiments can be maximized through remote terminals.

He characterized a major objective of the fields of planetary exploration, astronomy, and the Earth sciences as the achievement of a predictive capability to understand the planet Earth and the interactions between its biogeochemical systems. Dr. Hinners emphasized that many of the future roles of space and Earth sciences must be given direction by interagency, interdisciplinary and international coordination. The interactions between the ocean and the atmosphere, for example, may be so strong that coordinated national and international capabilities must be brought to bear on understanding the Earth's systems within a common long term strategy.

PANEL ON SOLAR TERRESTRIAL SCIENCE

Dr. James Van Allen, University of Iowa, Iowa City, Iowa

Dr. Van Allen characterized the current and future health of the space and Earth sciences as being jeopardized by a decline in budget since the Apollo program and the reality of the present "zero sum game." That is, major increases in one part of NASA's budget must necessarily be accompanied by major decreases in other areas. Dr. Van Allen expressed particular concern in this regard over the Space Station. The magnitude of the budget for the Space Station implies, in his view, hard times for the science community.

In written testimony Dr. Van Allen also outlined his concern over the increasing cost of major science missions such as the Hubble Space Telescope, Voyager, and Galileo projects. These, he suggested, tend to squeeze out the smaller scale, more flexible missions which have traditionally nurtured the space sciences.

Dr. Stamatios Krimigis, Applied Physics Laboratory, John Hopkins University, Laurel, MD

Dr. Krimigis described the activities of the National Research Council's Committee on Solar and Space Physics which he chairs. This NASA Advisory Committee has developed a strategy document setting forth priorities in solar and space physics similar to other major strategy reports in astronomy and planetary exploration designed to fit within overall established budgetary levels. Dr. Krimigis summarized the four major recommendations as: continuation of Upper Atmosphere Research Satellite and the Solar Optical Telescope; initiation of the International Solar Terrestrial Physics Program; planning for specific free flying missions such as the solar probe; and development of facility class instrumentation that would be attached to the Space Station. He suggested that this program could be carried out at a level of $300-$400M per year. Dr. Krimigis also expressed the view of the advisory committee that NASA does not now possess an organizational focal point for solar-terrestrial research. He urged an increased level of coordination in solar terrestrial programs within NASA.

Dr. Louis Lanzerotti, AT&T, Bell Laboratories

Dr. Lanzerotti discussed in anecdotal fashion the philosophical and practical underpinnings of solar terrestrial research. He provided a background description of the rapid advances that have been made in understanding the near-Earth environment. This has allowed much more sophisticated technologies to be utilized in space. Dr. Lanzerotti noted the direct relationship between the level of sophistication of space applications and the need for correspondingly sophisticated models of the near-Earth environment.

PANEL ON EARTH AND LIFE SCIENCES

Dr. Verner E. Suomi, University of Wisconsin, Madison, Wisconsin

Dr. Suomi provided an overview of critical measurements that must be made in the atmosphere and at the Earth's surface to improve our understanding of Earth and the interaction among its systems. He outlined the advantages of microwave sounding instruments on both polar orbiting and geostationary satellites in order to better observe atmospheric motions and provide input for models. He pointed to the need for coordinated measurements of ocean topography and surface forces. Observations and definition of the hydrological cycle, the sources and sinks of chemical constituents, and land surface features are required in order to obtain a comprehensive view of our environment. Finally, he emphasized that due to the large scale synoptic phenomena that must be studied, global participation in such programs is essential.

Dr. Francis Bretherton, National Center for Atmospheric Research, Boulder, Colorado

Dr. Bretherton outlined the fundamental philosophical basis for studying the Earth's systems. Traditional motivations such as natural scientific curiosity and potential practical applications have been augmented by the recognition that adverse anthropogenic effects on the environment must be thoroughly understood and controlled to maintain the Earth's delicate ecological balance. He advocated a program of long term observation, an archiving system for integrated and accessible data, and an organizational infrastructure which more clearly defines scientific roles and responsibilities. He emphasized that the implementation of an acceptable research strategy demands a common and shared perception of the magnitude of the problem.

Dr. Daniel Botkin, University of California, Santa Barbara, California

Dr. Botkin provided his perspective on the importance and advantages of studying biology from space. The concept that biology is a planetary characteristic, that life forms interact strongly with other geochemical cycles, and that large scale environmental changes are taking place, argue for the global perspective that can only be obtained from space. In addition, he pointed out that accurate and timely inventories of natural resources and surface features require utilization of space technology and remote sensing. Dr. Botkin emphasized the need for international cooperative efforts in research and monitoring related to these issues.

PANEL ON PLANETARY EXPLORATION

Dr. Lew Allen, Jet Propulsion Laboratory, Pasadena, California

Dr. Allen's testimony outlined the planned observations and accomplishments for the next several years which will climax three decades of planetary exploration. He described the anticipated rendezvous of Voyager-2 with Uranus in January, 1985 and with Neptune in 1989. He also described the Galileo mission to Jupiter and its moons planned for launch in May 1985. He outlined the future Venus Radar Mapper (now called Magellan) and the potential to compare the crustal dynamics of Venus with those of Earth. The Mars Orbiter, planned for 1990, will investigate in more detail the potential role of volatile materials in interacting with the Martian surface on more detail.

He also discussed plans for a potential comet rendezvous by a Mariner Mark II spacecraft in which a great deal of detailed information on the comet's composition and life cycle would be obtained. Finally, he reviewed the accomplishments of the IRAS mission with particular emphasis on an analysis of the star Delta Pictoris which showed evidence of the existence of a solar system. This is a discovery of profound significance which demonstrates the value of the planetary exploration program.

Dr. David Morrison, University of Hawaii*

Dr. Morrison, speaking as the Chairman of the Solar System Exploration Committee, emphasized the need to adhere to a cost-effective, carefully-formulated strategy for solar system exploration in order to avoid the hiatus in major missions which occurred over the past ten years. The execution of a minimum-level core program, he asserted, would sustain our technical capabilities, maintain scientific interest and productivity, and promote the training of new planetary scientists. He expressed particular concern over the possible deviation from this strategy during the next fiscal year because this would signal a return to the former, less productive system of individual mission advocacy.

Dr. Morrison also outlined the scientific goals of an enhanced program which would include a Mars sample return. These and other objectives of the planetary exploration program would, he said, lead to a greater human and scientific presence in the solar system, and would be a direction in which our society should move.

PANEL ON ASTRONOMY AND ASTROPHYSICS

Dr. George Field, Center for Astrophysics, Cambridge, Massachusetts

Dr. Field outlined several major accomplishments in the field of astronomy and drew analogies between the fundamental motivation to understand the universe and the objectives stated by previous witnesses to understand the solar system and the Earth. Dr. Field also spoke as Chairman of the Astronomy Survey Committee which set forth a strategy

* Currently with University of Arizona, Tucson, Arizona.

for astronomy in the 1980's and 1990's. The main feature of this strategy was the proposal for four facility class observatories, the Hubble Space Telescope, the Gamma-Ray Observatory, the Advanced X-Ray Astrophysics Facility (AXAF) and the Space Infrared Telescope Facility (SIRTF). Dr. Field pointed out that AXAF and SIRTF have not proceeded as quickly as planned and that the moderate missions such as the Solar Optical Telescope have been jeopardized by funding shortages.

Dr. Field concluded by describing the follow-on strategy for astronomy for 1995 to 2015 in which the principle of interferometry (combining the signals from two or more independent telescopes) would play a major role.

Dr. Martin Harwit, Cornell University, Ithaca, New York

Dr. Harwit reviewed the fundamental scientific philosophy underlying the plan for the four great observatories. Major discoveries, he testified, are directly related to instrument improvements in spectral sensitivity, angular resolution, temporal resolution, etc. The four great observatories are intended to provide observations in spectral regions and at resolutions not previously available. Dr. Harwit characterized these facility class instruments as meeting the essential needs of the astronomy community for the foreseeable future.

Dr. Harwit also provided an analysis of the impact that the operation of these facility class instruments would have on the overall NASA budget in astronomy and astrophysics. He pointed out that a healthy plan of new ventures could be maintained with a gradually increasing budget pegged, for example, to the growth in the gross national product.

Dr. Jeffrey Hoffman, Astronaut, Johnson Space Center, Houston, Texas

Dr. Hoffman provided his perspective on the future of performing science in space from his standpoint as both a scientist and an astronaut. He emphasized the educational role that space assets can play both in inspiring a fascination with the space program and in establishing increased opportunities for students to perform science experiments.

Dr. Hoffman characterized the current state of the science of astronomy as critically dependent on the acquisition of larger, more powerful instruments with specific spectral and time resolving capabilities. He asserted that these unmanned observatories would not be feasible without the capabilities provided by the Space Shuttle.

He also testified that it is essential that astronomers be provided adequate flight opportunities in the small and intermediate payload range in order to train new scientists to use space technology. He said that present flight opportunities are limited. He emphasized that the flight opportunities and science capabilities of the Space Station should be maximized during the design process.

Scot Thomas, Utah State University, Brigham City, Utah

Mr. Thomas provided his perspective on the science utilization of the Space Transportation System by small payload users. The lack of small and intermediate payload flight opportunities results in long lead times and overly complicated and expensive experiments. This does not provide the traditional environment to allow the interactive process which best serves scientific progress. Major limitations, in Mr. Thomas' experience, relate to storage space, crew workload, and duration of the Shuttle mission.

Mr. Thomas stressed that in planning for the Space Station the tendency to conceptualize all science utilization as Spacelab class payloads must be avoided. He described the ideal environment for the Space Station in terms of a traditional scientific laboratory which would promote a learning process. He characterized the man-in-loop capability as essential, based on past experience.

III. MAJOR ISSUES

The underlying objective of these hearings on the future of the space sciences was to review the past accomplishments in various fields of science related to space. Due primarily to the wide diversity of scientific disciplines which study space or have benefited from the space program, it was not possible to address all areas in a comprehensive manner. However, during the course of these hearings certain themes were recurrent and appear to be generic with respect to extending our scientific capabilities into space.

A. Scientific Cooperation with the USSR

An issue which was characterized as of major significance by each panel was the relationship between the U.S. and other spacefaring nations, and in particular the USSR. Clearly, the capabilities and potential contributions of other such nations have improved dramatically over the past two decades.

These hearings were held just before the Subcommittee went to the Soviet Union with the stated objective of seeking to open the door to renewed cooperation in space. Several witnesses were asked by Chairman Nelson to provide their own views concerning what form this cooperation should take.

In commenting on the overall objective of maintaining U.S. leadership and also achieving international cooperation in space activities, Dr. Hinners characterized the overall benefits that have accrued from joint efforts with Canada, Europe, the United Kingdom, and the Soviet Union. However, he expressed the following concern:

> "...I worry a bit about it. I worry sometimes that international cooperation is seen by some people as

> strictly a mechanism by which to reduce the cost or the budget to the U.S. for the conduct of space science. That reduction [of] cost is real, and that's good. But I think, as we look at international cooperation, we must continually ask ourselves: Where should we do it? What projects are really best suited for it? Where do other countries have an expertise which may be even better than ours? Where should we maintain our leadership? I would not like to see our activity diffused totally across the board in terms of cooperation, but to take certain areas where we do maintain a strong leadership and put priority on those in our U.S. space science program..."

In response to Chairman Bill Nelson's request for recommendations regarding cooperative efforts with the Soviet Union, Dr. Sagan articulated a specific major program. He described a scenario in which the U.S. and Soviets might undertake a joint manned mission to Mars with the scientific objective of returning a Martian sample. He emphasized, however, the social and political benefits of such a mission:

> "...Imagine the construction with the equivalent of one or two dozen Shuttle payloads of an interplanetary transfer spacecraft in earth orbit--of course, every construction step there on the evening news. U.S. and Soviet welders are equivalent working together. Then the spacecraft is finished; then on its way to Mars in a, I think, extraordinary apt metaphor of the condition down here. The U.S. astronauts would have their lives dependent on the Soviet cosmonauts doing right and vice versa....
>
> ...I maintain that such a mission would be a powerful token of the United States and the Soviet Union wishing to turn around the present quarrel which has threatened now everyone on the planet."

During questioning, Chairman Nelson asked if there were any interim steps that should be taken in preparation for such a mission. Dr. Sagan described an array of potential cooperative efforts ranging from joint search and rescue missions to cooperative planning for scientific missions in unmanned planetary exploration.

In commenting on Dr. Sagan's proposal Dr. Hinners agreed and characterized the apolitical nature of science as an appropriate forum to promote a greater degree of inter-cultural contact and communications. He also pointed out that resources used for the exploration of the Moon, Mars or asteroids, for example, would be preferable to those same expenditures on defense activities.

Dr. Hinners cautioned that any major commitment should be well supported by the political process. He said:

> "...I think that the United States has not always been a very good partner in space collaborations with our western allies. We have delayed programs. We have cancelled programs, such as the International Solar Polar Mission, now called Ulysses. And I think it would behoove us to learn from past mistakes and, if we did proceed with new ventures with the Soviet Union, be they something as grandiose as a manned Mars mission ultimately or probably in the near-term the ISTP program, [International Solar Terrestrial Physics Program] which I think is ideal for such a thing, we should make sure that our political system allows us to proceed in an orderly fashion; that our international collaborators don't suffer great harm to their programs and to their financial investments, be it the Soviet Union or western Europe...."

Dr. Krimigis provided his perspective based on his own involvement in the International Solar Terrestrial Physics program. He said:

> "...We have to learn how to work with scientists from the Soviet Union, and it would appear to be exceedingly difficult to undertake a major program, even the one on an unmanned sample return, let alone a manned program, before we have learned how to do sort of smaller programs which are relatively decoupled from each other in terms of the technology and the kinds of concerns that exist today vis-a-vis the Soviet Union.
>
> I believe the [ISTP] Program will be very useful in that regard...."

This theme, in which scientist to scientist exchange was characterized as the foundation for cooperative agreements, was echoed by Dr. Morrison. He said:

> "...I think that we have had a very difficult time in dealing with the Soviets during the last few years because there has been an almost total breakdown of official contact, and, therefore, on both sides individual scientists have continued this communication, but under certain amount of stress and difficulty. And we need to rebuild our bridges."

Dr. Morrison advocated a series of specific programs that could serve as the basis for rebuilding those bridges. He mentioned data exchange from the U.S. and Soviet Mars missions in the early 1990s, the investigation of Venus and other coordinated efforts.

In the field of astronomy, Dr. Harwit described some additional types of missions that could also serve to increase the level of cooperation and scientific contacts. He said:

"...unique opportunities exist for meshing the individual nations, these observatories would be dovetailed in a systematic way so that we cover all of the areas that we want to cover to make sure that there are no gaps. It will require collaboration both between agencies and between individual scientists, and I think we should try to pursue that with as much vigor as we can..."

A different point of view was offered by Dr. Allen who reviewed the historial and technical relationships between U.S. missions and their Soviet counterparts. He described how the technology in Soviet programs in astronomy and planetary exploration has been improved and how the involvement of Soviet scientists in reporting data and in collaborating with other scientists has increased markedly. He pointed out, however, that the phasing of Soviet programs has resulted in a major challenge to U.S. science. He offered the following analysis:

"...One gets the feeling that the Soviets, recognizing the particular competence of our Academy structure in formulating objectives and strategies for investigating the solar system, have profited from that by picking out from the list of things we've identified as most important to do those which they can do; doing them substantially quicker than we can do them.

Now that's awkward. It causes many questions to be raised about our program. We need to find ways of accommodating to that better, either through cooperation, through better communication, through some way of having our programs be more rational. There is really no point in racing to do the same scientific observations...."

Dr. Allen summarized by pointing out that regardless of the quality of the Soviet missions, their program is ahead of the U.S. program in many areas. He described several potential approaches to regaining our leadership role such as narrowing our science objectives to only those areas where our technological abilities assure the U.S. of a unique role. His preference however, was clearly for a policy of mutually informing and rationalizing the efforts each country undertakes. He concluded that the U.S. will be forced to enter into such a relationship with the Soviets, if for no other reason than our mutual collaborative role with the Europeans.

Thus, although each witness characterized different objectives for establishing cooperative agreements with the Soviet Union, there was a fair degree of unanimity regarding the means by which these objectives could be achieved, that is, greater scientist-to-scientist collaboration. There was also a surprising degree of agreement regarding specific science missions which could be candidates for future cooperative efforts. It must be stressed however that the witnesses represented a somewhat limited perspective, reflecting primarily science concerns. In a broader context, other political and policy issues must be carefully considered.

B. Need for a Global View of the Earth Provided by Space Platforms

Over the past several years the utility of space in studying the Earth's systems has become increasingly important. In recognition of this, legislative actions such as the Land Remote Sensing Commercialization Act of 1984, and the Committee's amendment to the National Aeronautics and Space Adinistration Act, 1985 to add expansion of human knowledge of the Earth to NASA's mission, have sought to enhance NASA's role in this area. In addition to the scientific focus such legislative actions have accomplished, several witnesses outlined other needs for international, interdisciplinary and interagency coordination which are strongly related to the overall objective of utilizing space in the most effective manner possible.

The philosophical basis for this view was expressed by Dr. Suomi as follows:

> "...One must convince the hard-pressed farmer in the Midwest that it really makes sense to observe the middle of the equatorial Pacific ocean, as the recent El Nino has taught us. We must look beyond our city, county, state, or even our country, and press for the global view... We must remember that Earth is a planet, too--a very precious one to each of us. We want to learn about the future well-being of the Earth. As the Europeans are saying with a very nice document, Look Downward, Look Forward. We ought to join them and others throughout the world to better understand our complex, but precious earth and how it works..."

Chairman Nelson, in pursuing this thought with other witnesses, solicited Dr. Botkin's opinion on how international cooperation could be promoted. The following dialogue took place:

> Mr. Nelson: "Dr. Botkin, international cooperation, do you think it would be improved if we had s[illegible]d of international research center?"

> Dr. Botkin: "Well, I have to think that, because that's what I'm involved in. Yes, I think that scientists--as people get involved in questions and they get intrigued by questions. And they begin to cooperate. And the problems of working between nations among scientists will disappear over the issues. So if you have an international research center and there are certain questions posed that scientists get interested in, then the international problems go away at that level..."

The importance of international cooperation was also articulated by Dr. Bretherton who emphasized that our environment is changing in ways which are not well understood and will require worldwide attention. Dr. Bretherton also described the additional necessity for interdisciplinary research in resolving these problems. He said:

> "This challenge requires a new perspective on studying the Earth. Traditionally, the Earth sciences have been divided into a number of disciplines. Vern Suomi would say his major area of interest was the atmosphere, and Dan Botkin would talk about global biology. But we're going to need people who are able to look much more broadly than that and really understand the interactions between the atmosphere and the ocean; the interactions between the climate and the biology; the way the biology is responsible and controls some of the gases like methane and carbon dioxide going back into the atmosphere, which in turn affect our climate; the role of the ice and solid rocks in all of this. These are the sorts of problems we have got to learn to address. And, frankly, we're not set up to do it.
>
> This challenge requires a global view, taking advantage of the unique opportunities we can get from space, but also requiring a systemic study of the processes using every tool at hand, including the *in situ* observations."

Similarly, Dr. Hinners, in his testimony, characterized the role of NASA's research satellites in providing data which must be analyzed from an interdisciplinary standpoint and used in the decision-making process. He said:

> "...We're seeing with our research satellites that the ocean and atmosphere have a very intimate connection; that one cannot study the oceans in isolation nor study the atmosphere in isolation. The feedbacks, the interconnections are just too strong.
>
> Satellites promise a global perspective, a time series of measurements in many areas of the spectrum, so that we can look at, say, a cloud cover at the same time as ocean temperature, feed them together to put into our models. I say, "models." Models of what? These are models which generally are based on computer developments, technology; models which allow us to predict the behavior of the major atmospheric or ocean systems. And, indeed, that's where we're trying to get in earth sciences--is to a predicitive capability, to understand well enough where our major systems are going so that we can take the correct political and social actions downstream."

Dr. Hinners also emphasized the need for interagency mechanisms that would provide an adequate focus for this type of research. He explained:

> "...We must have a coherent long-term strategy which is now being worked. It's a strategy which goes beyond the space agency. NASA itself has no grip on research from satellites. There is no reason, of course, why NOAA, why the Department of Interior, or anybody else, can't launch and use a satellite to collect basic scientific information relative to their roles. What is required is that we have a bringing-together, a coordination of this activity, and agree on how we're going to make progress toward understandirg Earth as a global system..."

Some witnesses cited natural organizational barriers which have acted to the detriment of such interagency coordination. In response to questioning by Congresswoman Jan Myers (R-Ks), Dr. Bretherton enumerated several factors that must be addressed in eliminating these barriers. First there must be a common sense of priority by all of the agencies involved in applying their respective resources. He described NASA's role as one of research and development of space applications which takes place over relatively short time scales. Long term roles are the responsibility of the National Science Foundation (NSF) for sustaining support in basic research, and the National Oceanic and Atmospheric Administration (NOAA) for long term monitoring and observational services. In summarizing he said:

> "So what you're seeing here is that to put together the pieces we've got to exploit the traditional roles of those three agencies, because all of them are essential."

A similar opinion was expressed by Dr. Hinners. In discussing the relationship between NASA and NOAA he said:

> "...There's a lot of fundamental things about the data processing that could be done, could be done relatively inexpensively--and are not being done because of the way we set priorities within our system.
>
> We require, for example, that the different Federal agencies work together to achieve these long-term roles. I'm not just talking NASA. The major operational systems we are talking about are, in fact, operated by other agencies--by NOAA, and by the Department of Defense. We need to make maximum use of that data, also the data that's available from the commercial sector."

Thus, rather than any substantial revision in agency roles, Dr. Hinners stressed that the existing agency infrastructure allows the critical research and observational programs to be accomplished. Dr. Hinners asserted, however, that each agency must be in a position to live up to its stated role. He summarized by saying:

> "I cannot emphasize this point too strongly because at this moment our Federal structure appears from the outside to have cast a mold for NOAA which essentialy focuses on short-term services--weather prediction, immediate cost-benefit analysis--and totally ignores these long-term issues of which...only NOAA is in the position to do what's needed. We also have a fundamental role for NSF in terms of supporting the basic research into the process concerned."

Finally, Dr. Botkin, in commenting on the role of NSF, said:

> "...NSF operates in very disciplinary lines, and it's notorious among my colleagues that whenever they try to put in a proposal which is between disciplines, no panel will take it because it falls through all the cracks..."

In discussing this issue, Chairman Nelson solicited the views of witnesses concerning the International Geosphere Biosphere Program (IGBP) recently proposed by the National Academy of Sciences. The philosophical and scientific basis underlying this program bears a close similarity to the objectives advocated by the witnesses for an international, interagency and interdisciplinary framework. The following dialogue took place:

> Mr. Nelson: "...Do you think that the International Geosphere-Biosphere Program is an appropriate vehicle to coordinate international research efforts?"
>
> Dr. Bretherton: "...It's too early to say, in my view. As I see our problems of international coordination, there are three things that have to be done:
>
> First of all, there has to be a forum in which scientists from the various nations of the world can effectively meet together to discuss what the scientific problems are, to discuss strategies for approaching those problems, to get some sense of priorities so that they can go talk to their own governments about things in some sort of coherent, unified way... The second thing that's needed is...an intergovernmental framework to deal with at some level, routine, but at other levels, terribly important issues like data exchange, exchange of scientists,

> access, for example, by ship to someone's exclusive economic zone to go and take measurements for this program... The third type of international collaboration that's needed, particularly in the space area, is bilaterals, which are fundamentally aimed at saving costs..."

A similar response was given by Dr. Botkin who said:

> "I agree with Francis--it is too early. It's a little bit like parents expecting a child and discussing what medical specialty their offspring will go into--to ask if it's yet the right vehicle, because it's still a pregnant idea, I think.
>
> It has the potential to fill this first need, this need for a forum. I think in getting the right kind of international cooperation you need a forum for discussion, and then you have to have actual research institutes and a planetary observatory for observing, the sort of thing we're hoping we can develop in Venice, and you have to have systems for managing the data and sharing the data. And you need those three aspects of any program.
>
> The IGBP could be part of the first, and there's enough precedence for it, and it might succeed, but for it to succeed it needs to obtain sufficient support from enough nations of the world. And its not clear that at the national level, not just the scientific level, there's truly political support and financial support. It has to develop ways so that the research would actually be funded and so that there was clear agreement about what would actually be done, and there has to be the kind of balance that needs to be obtained."

Thus, notwithstanding the stated need for an international, interagency, interdisciplinary research program, the witnesses were equivocal with regard to their endorsement of IGBP at this time, although none opposed IGBP.

An associated issue which was linked to the need for such coordination was the establishment of a global data base that would be accessible to a broad range of scientists. Dr. Bretherton, in his testimony, outlined the scientific significance of such a data base. He said:

> "...We also require an integrated information system where we don't just go out and measure something, remember it for a few years, and then forget, because our biggest problem here is to be able to come back 20, 40, years from now and look back at what's happening now and saying: are the changes we think have taken place over those 20, 40 years are they real?

> Are they just an artifact of the way we took the data or the way we processed it, or have we simply just forgotten?
>
> And, frankly, 99.9 percent of what we learn at this moment is forgotten. It is not remembered in this way. And this, in turn, is going to require fundamental changes in our whole way we archive information and preseve it for posterity in useful ways..."

Dr. Suomi's comments on this issue provided insight into enabling technologies that may support such a global data base. He said:

> "...Thanks to private industry, we now have some fantastic tools for assembling and storing and making available data in both the recording media--the new laser disks and so on--as well as the computers with which to extract them...
>
> And so I think if we followed some of these initiatives things would fit into place because of the need to have certain formats and standards, and so on. Otherwise, if we went off on our own direction, it would--it might be a step backward. If we don't do it carefully, the important science will be lost in the records as well as being lost in nature, and so the records must be available."

Thus all witnesses were unequivocal in their view that space platforms offer a crucial vantage point from which to study and monitor the Earth's biological, geological, and chemical systems. In order to properly capitalize on this capability, however, the witnesses described a myriad of administrative and political challenges which must be overcome. These are related to the need for international, interdisciplinary, and interagency coordination in planning, collecting, and disseminating space-derived data. These challenges appear to be substantial and endemic to the cultures of the scientific disciplines, the Federal agencies, and geopolitical relationships.

Of significance, however, one central element of the various approaches advocated by the witnesses appears to be a common global data base. In addition to achieving the technical objective of providing a consistent time-series of global data, such a system may also have benefits in promoting the interdisciplinary, and possibly the interagency, and international coordination goals articulated in testimony.

C. The Relationship among Operational, Research, and Commercial Programs

The Land Remote Sensing Commercialization Act of 1984 established the intent of Congress that the Federal agencies and the private sector work together to maintain a vigorous and coherent program which promotes the flow of technologies from the research to the operational, and, if appropriate, to the commercial phases. This intent was clearly related to the perception that our investments in space technologies are now maturing to a stage that they can be more fully integrated into the private sector. This would suggest that the interfaces among NASA, other agencies, and the private sector must be fully defined and flexible enough to promote not only the transfer of technologies, but also the sharing of organizational roles.

In addressing this issue in the context of the Landsat commercialization legislation, Dr. Bretherton said:

> "...I believe that the Commercialization of Space Act was fundamentally right, the right way to go, but what I'd like to point out is that, in terms of implementing it, there are some serious unresolved issues associated with the fact that the members of the community--the academic community, the private sector, and the Federal agencies--simply have not yet had time to evolve a set of working relationships or working understandings about who does what..."

In expanding on this theme, Dr. Bretherton described several specific areas in which the lack of clearly defined working relationships has had an adverse impact on the achievement of national goals even though such goals may be held in common by all parties involved. For example, Dr. Bretherton explained that EOSAT, a private sector company marketing Landsat data, has encountered difficulty in providing data grants to researchers, despite the perception that research results may ultimately enhance market development. Another difficulty described by Dr. Bretherton relates to the degree to which NASA should develop a technology before it becomes appropriate for commercial development.
Dr. Bretherton summarized by saying:

> "We have no guidelines as to where those interfaces are, and what is desperately needed over the next three years or so is a forum in which these issues can be talked out, a forum that has representatives on it from the academic community, the private sector, and the Federal agencies concerned, and there are several of them..."

Dr. Hinners also commented on the roles of research programs and the difficulty in transferring research programs from the experimental to the operational phases. He said the following:

> "The Landsat, looking at the earth with multispectral sensors, evolved out of research programs. Some of those programs have now become what is called operational. It's a shame in a sense that they've taken on that characteristic, because those same programs

> still supply very valuable, much-needed scientific research data. And, unfortunately, that has also led to a lessening of the scientific research satellite for Earth applications in many areas."

Dr. Bretherton offered another example of the relationship between research and operational programs in his testimony. In describing the data needs for a global monitoring system for long term ecological change, he said:

> "...In some cases it's going to need new observing techniques. We can't make all the measurements we need to make. In other ways, just as important, it's going to require actually making use of observation systems we routinely have in place now. The weather systems, weather satellites, are an extremely powerful tool for this purpose, but they're almost useless for long-term observations because they're not calibrated properly. We can't track what's going on..."

With respect to commercialization of space data systems, some witneses expressed concern over the potential loss of science data. The following exchange between Congressman Robert S. Walker (R-PA) and Dr. Suomi characterized this issue:

> **Mr. Walker:** "Dr. Suomi, do you think we can ever consider privatizing meteorological satellites, and what would be the impact on science if we did that?"
>
> **Dr. Suomi:** "I think the impact on the science would really be tragic because meteorological satellites, the operational ones, form the database for much of the research. Actually, those pictures [of a hurricane] which were mentioned as being in view in Florida and so important came from the University of Wisconsin where I am. And so NOAA helped support this work, but I think the interface between research and operations would be ruined..."

Mr. Walker pursued this line of questioning by hypothesizing that commercial entities may be motivated to invest in various forms of applications research in order to enhance market development. Such applications, he asserted, could also lead to higher quality basic research.

Chairman Nelson also questioned Dr. Suomi on the dual role of meteorological satellites as platforms for research and operations. The following dialogue took place:

> **Mr. Nelson:** "Dr. Suomi do you think there should be a balance between operations and research on the meteorological satellites?"
>
> **Dr. Suomi:** "Yes, I do, for the following reason:

> there are two elements in the observations from space which we need in meteorology and oceanography as well as some of these other things. One is what might be called the initial conditions of the atmosphere or the initial state of the climate, and so on. Those are the operational ones which have to go on and on.
>
> But in order to develop the instrumentation that will allow us to understand the processes which are responsible for changes in those boundary conditions, we need another kind of satellite which can observe processes. These do not have to go on forever, because once we learn how the process works and we can state it mathematically, one can go from there."

A similar view was expressed by Dr. Bretherton who also emphasized the need for a focus on applications research. He said:

> "...I'd like to extend what Vern Suomi said about the need to supplement the operational instruments by remarking that a lot of the things that we're talking about actually take place in the data processing, and a somewhat broader view at the processing end would make a lot of difference to attaining our long-term objectives at the same time as our short-term ones, for a very, very small increment in cost."

Another perspective on how instrument platforms may be configured to serve both research and operational roles was put forth by Dr. Bretherton. He said:

> "...In the long run I think the space station platforms, part of the space station complex, really do provide a unique opportunity for part of the totality of what we're talking about. They provide the opportunity, first of all, to plan instruments and data systems from the ground up with a view of a continuous sequence of flying a research instrument or flying an instrument in a research mode perhaps, learning how it works, learning how to process the data, and then transferring it <u>in situ</u> into an operational mode without having to completely restructure the whole organization, the whole data system that surrounds it."

Finally, Chairman Nelson asked several witnesses whether the current level of applications research in remote sensing was adequate. The following dialogue took place between Chairman Nelson and Dr. Botkin:

> Mr. Nelson: "Are we doing enough applications research for remote sensing?"

> **Dr. Botkin:** "No. That's the short answer, but there's a lot more to it than that.
>
> I think that there's--some of the problems we've had with applications in the United States is that there's a lot of confusion about what applications means, and then this gets into whether things are funded or not. So a semantic problem becomes a real problem in terms of funding.
>
> For example, to some people developing an instrument is research and using it in science is applications. For scientists, using the instrument in science is research and applying it, say, to finding out where Canada's economically useful forests are might be an application. To research management, finding out those forests is research, not applications."

Dr. Botkin also drew a parallel between the need for applications research in remote sensing and other applications areas which have more well developed research programs. He said:

> "I think that there's a lot of things that are to our Nation's interest to know about. I think that, just as we have a U.S. Geological Survey and we have a Weather Service that tells us where the weather is -- what the weather is -- it's just as important to a nation to know its distribution of biological resources and mineral resources. And if that's an application, it's also a vital national interest. And so we should be fostering research and the development of techniques for those things as well."

From the witness testimony, it was clear that a great deal of confusion exists about the roles of the Federal agencies and the private sector at the present time with respect to data systems. This confusion may constitute a genuine impediment to broadening the utilization of space technologies.

In many examples cited by the witnesses, the Federal-private sector infrastructure does not appear to capitalize on major attributes of data system, especially in remote sensing. It is clear that, for a small increment in cost, space platforms can be planned to serve as both test beds for experimental instruments and also permanent facilities for operational instruments. In addition, because agency missions may be too narrowly defined, poorly coordinated, or too inflexible, an inadequate program appears to exist for applications research in the remote sensing area. Such research could make valuable contributions for a relatively small additional cost which would more fully capitalize on the investments made in space hardware systems. These contributions could benefit the science community, the general public, and the commercial sector.

D. The Role of Space Science in Education

Many witnesses pointed out that a major benefit of the nation's investment in the space sciences was in its educational value. Although the mission of NASA is not specifically to support educational institutions, clearly the quality of the nation's space science program directly depends on the quality of scientists produced by the educational system. In a larger sense, the quality of our whole establishment depends on the strength of our educational system. Students inspired in the space sciences may also form a valuable resource for other societal needs, both scientific and non-scientific. Thus there is great value in establishing a close relationship between NASA and educational institutions.

In describing the philosophical underpinnings which have motivated our pursuit of space science, Dr. Hinners said:

> "...One might ask occasionally, of what use is this? And I do get the question posed. A scientist might be tempted to say 'knowledge for the sake of knowledge.' And I would take great issue with that kind of response. To me, it is much deeper than that, particularly as we look to see where society is headed today, with a major goal of educating our people, especially our youth.
>
> We're making our youth, our people, into a very curious people, taking advantage of the epitome of evolution, if you will, at this point in the mind of man."

In later testimony, Dr. Hinners concluded:

> "The youth in our schools are excited about space science and exploration. It encourages them to take careers in engineering or science. Whether or not they ever end up as space scientists is really immaterial. It provides a basis, a reason for studying, for working--not just in the sciences, but in the humanities--to understanding where...mankind is headed."

Dr. Allen, in outlining the role of the Jet Propulsion Laboratory in planetary exploration emphasized the educational aspects in saying:

> "...The mission that we're assigned is to explore our solar system, and we've done that for the last 25 years, have visited most of the planets now, obtained a good deal of science information of great value, and I think also brought back some of the drama and beauty of the solar system in which we live in a way that has been an inspiration to young people and of great value, I think, to the education process and to

the understanding of the public science..."

Dr. Hoffman in his testimony drew a similar conclusion and described his own commitment to the space program as having its genesis in youth related activities. He said:

> "...Only this past Monday, I was up in New York taking part in the celebration of the 50th aniversary of the Hayden Planetarium. They've had about 25 million visitors there since the planetarium opened. It's certainly the place where I cut my teeth as a young child and got interested in astronomy.
>
> They did have several hundred school children among the invited guests, and I would like to say that I think that when we look at some of the benefits that we get out of space research and the space program in general, aside from all the spinoffs, all the things which we can at least try to quantify, one thing that is absolutely impossible to put a number on is the inspiration that young people all around the country get."

Dr. Hoffman also drew a direct correlation between these educational objectives and the opportunities provided by the Space Shuttle. He said:

> "...I think one of the other most important things that we can get out of doing experiments on the Space Shuttle is the opportunity that it gives us to train the new generation of space scientists. It certainly is extremely valuable from a scientific point of view to have graduate students work on data coming back from these large observatories. You can get tremendous scientific return from that, and it's a very exciting thing for a student to work on."

Thus, from the witness testimony it was evident that the educational role of space science is perceived as twofold. First, achievements in the space sciences contribute to the broad education of the public and justify to a great extent the expenditures made. The benefits of this education are diffused throughout our society. Second, it is also a major stimulus to younger scientists to enter the space program and provide continuity in our scientific human resouces. From the witness testimony, it was clear that any major discontinuities in flight opportunities would have adverse consequences in both of these areas and would impact our world leadership position in space.

E. Adequacy of Flight Opportunities in the Current Space Program

From the above testimony, it is apparent that it is incumbent on NASA to ensure that a continuing and robust relationship is maintained between the space program and our educational institutions through the provision of adequate flight opportunities. Thus it is appropriate to examine the perceptions of the scientific community with regard to the adequacy of flight opportunities for various classes and types of payloads. In examining this issue, the Subcommittee was congnizant of a shift in emphasis in recent years from suborbital programs such as sounding rockets to Shuttle-compatible payloads.

Dr. Van Allen, in responding to Congressman Harold Volkmer's (D-MO) questioning regarding the value of major science missions, said:

> "...I have a very deep dedication to major missions, but I just hope that they are not the only thing we have. I hope we have room left for some rapid response, flexible missions in the sounding rocket--small satellite program. I think they have a very important function.
>
> As you know, I make my career in the university. I'm very sensitive to the participation of my young colleagues, the students and younger colleagues, and I perhaps represent that point of view more than anyone else here today, ..."

Chairman Nelson pursued this point and asked Dr. Van Allen to characterize the consequences of his assertion that the sounding rocket program was in decline. Dr. Van Allen said the following:

> Sounding rockets are relatively inexpensive. They're relatively rapid. We can probably in the course of a year build an experiment for a sounding rocket and have it flown and that data acquired.
>
> In the space flight business these days, it more resembles a decade. I think that's one of the greatest barriers we have to follow-up work--is the enormous delay of major missions these days. So the sounding rocket fills that gap. They fit in with the university-style work.
>
> In my own personal experience, a graduate student can help devise the experiment, help with the field work and conducting it, get the data back, analyze and interpret the results, and have a Ph.D. thesis on the basis of his work--all within a three-year period. That is totally out of the question with major missions these days. It's one of the most precious experiences that I think any student can have who aspires to this field."

A different point of view was offered by Dr. Hoffman with respect to the astronomical sciences. He described the relationship between the sounding rocket program and the Space Shuttle in the following way:

"...How do we train a generation of astronomers in how to use space technology? I think without the opportunities to fly fairly frequent and modest experiments--and I think the Shuttle is the way to fly them now--we lose this opportunity. This is the sort of thing that traditionally has been done using balloons and rockets.

But I think as technology in astronomical observations has improved, the ability to do really useful science from, certainly, rockets has dimished tremendously. I think there still is a fair amount of useful work that can be done from high-altitude balloons, but for astronomical purposes they are somewhat limited, certainly in most wavelengths. And the Shuttle is, I think, the hope of the future.

Dr. Hoffman went on to explain that NASA and the science community, recognizing the need to capitalize on the capabilities of the Shuttle, have begun programs such as the Getaway Special, Spartan, and Hitchhiker which are meant to accommodate small and intermediate class payloads.

In describing the shortcomings of these Shuttle related programs, however, Dr. Hoffman said:

"...I think the problem is they have been so slow in getting started that we really have not developed the capabilities to replace the opportunities which traditionally astronomers have had using balloons and rockets. And things really have been difficult, I think, now for ten years to achieve the level of small-scale experimentation which was done so readily when I was a graduate student.

I think that that is a gap in our capabilities at the moment. I hope that the Spartan program will continue to accelerate. Unfortunately, when you look ahead at the number of flight opportunities which we actually have scheduled, it's very limited, and it has not been able to pick up the slack left by the dimishing capabilities of the rocket program..."

Thus, the testimony of Dr. Van Allen and Dr. Hoffman, while in agreement over the end objective (the need to increase flight opportunities), differed with respect to the best approach. Their differing recommendations raise the following question: Should we revive the sounding rocket program or enhance the Shuttle-based programs? Chairman Nelson solicited the view of Dr. Field in this regard. Dr. Field said:

"...I would agree with Dr. Hoffman that planned transition from sounding rockets to Spartan and other types of activities aboard the Shuttle is crucially important to bring about. It has been delayed unnecessarily, in my opinion.

The point was that the rocket program has been phased down by NASA, and the corresponding programs for small activity, smaller experiments, have not been made available yet on the Shuttle. That's how it affects astronomy. I am not sure how it will affect other fields..."

Dr. Hoffman provided a focus for this discussion by comparing the science merits with the operational flexibility for the sounding rocket and Shuttle programs. He explained that as a consequence of the short observing time available on a sounding rocket, faint objects can only be seen with relatively large aperture instruments that characteristically would exceed the payload capacity of sounding rockets. In addition, the number of objects that can be scanned is severely limited. In this regard, even the Shuttle mission duration is inferior to a free-flying satellite. However, the Shuttle offers notable advantages for instrument development and for training astronomers in new techniques.

He concluded by saying:

"...I think it's important to remember that in addi- to the great, grand projects of the astronomy of t. future, we have to keep nourishing the roots of the science by making it possible to do fairly frequent space observations and to give people the chance to develop new instruments, to develop new skills..."

Dr. Harwit agreed and emphasized this point saying:

"...I think the point that Dr. Hoffman is making is still the right one; namely, that one needs small instrumentation for training the next generation of scientists.

If we phase out the rockets, as we have been doing, and the balloons, we really have to pick that group up in the Shuttle, and as Mr. Thomas here has demonstrated, it is a place where students can do outstanding work, and it is also a place where we develop the instruments that will then be flown on the more expensive missions where those discoveries then eventually get made..."

During testimony one notable example of the adverse effect of a hiatus in flight opportunities was described in the following exchange between Chairman Nelson and Dr. Hoffman:

Mr. Nelson: Dr. Hoffman, since the Einstein X-Ray observatory went out, and until the time that we put AXAF up, that's probably a period of around 12 years. So the question is, what does that do to the X-ray astronomy community?

Dr. Hoffman: I think what has happened is that the focus of X-ray astronomy has shifted from the United States to other parts of the world. As Dr. Field mentioned, this was something of which we have great cause to feel pride of having opened up this field in this country, and I think it's been little short of tragic that we have lost this tremendous observational capability.

Dr. Hoffman compared this loss to the hypothetical case of having to close down all of the U.S. optical observatories. The only means of obtaining new X-ray data at present is through collaboration with the Europeans and Japanese.

He concluded by saying:

> "...In fact, the impact on a good number of observational X-ray astronomy groups in this country has been perhaps--well, I don't think catastrophic is too strong a word. There has been a withering away of a great deal of the expertise and the ability to construct space experimentation in groups that were once strong and thriving, and it's been the result of not having the opportunity to fly space experiments.
>
> Perhaps had the opportunity to fly some smaller satellites been made available or to fly some experiments on the Shuttle been made available at an earlier date, we would have avoided the loss of these capabilities..."

Mr. Thomas provided a valuable additional perspective to this discussion by describing his own experience as a small user of the Space Shuttle. In outlining the adverse effects of infrequent flight opportunities on a small science user he said the following:

> "...Infrequent flights lead to long lead times, and they also cause scientists to make the experiments very complicated. If you know you're only going to get one or two chances in a career, for example, to study something, you want to buid an experiment that will study absolutely everything you could think of. So that makes the experiment very complicated and very expensive..."
>
> "...Now, why is that bad? That is bad because that's not the way science is done. Science is an interactive process. One goes into the laboratory and does an experiment, and he looks at his data and de-

> cides that to find out more about his process he needs to study a certain aspect of it. And that's how science is done. It's not a one-shot thing. It's an interactive process.
>
> If you will only get to fly an experiment once, you're not going to know everything to look for even though you spend five or eight years designing and putting every kind of probe that you can think of, you still don't know exactly what might be the most interesting thing in what you're studying..."

Mr. Thomas pointed out that some of the most notable science accomplishments of the Space Shuttle such as the electrophoresis and protein crystal growth experiments, came not from infrequent Spacelab class platforms, but from frequent, interactive development flights. He said:

> "...So I would hope, in the future, that we could have more access for simple experiments on the Space Shuttle, and also don't let the Space Station turn into a big spacelab. Turn it into a real laboratory and make sure there is frequent access of equipment up and down and shift the emphasis to smaller experiments that are more simple..."

Mr. Thomas also provided insightful testimony regarding the value of man-in-the-loop in interacting with and maintaining these small and intermediate class experiments. Dr. Hoffman added his own perspective as a payload specialist and described the appreciable impact such requirements currently have on crew time given the relatively short mission duration for most Shuttle flights. He said:

> "...You will find down in Houston that some crew members and also flight trainers, people responsible for the manifesting, are sometimes somewhat resistive of adding a lot of things onto the Shuttle flight manifest because of the crew workload, the inherent limitations on time available to carry things out.
>
> But I think if you ask any crew member in the program if we were to give you an extra day in orbit, would you be willing to do the extra work to carry out six different middeck experiments, you'd get 100 percent agreement..."

Dr. Hoffman concluded that extended mission duration and additional middeck experiment space would be valuable improvements for small and intermediate class payloads.

In summary, it was clear from the testimony that some segments of the science community are not being adequately served by the available flight opportunities. In addition to the reduction in suborbital programs, the Shuttle has not yet achieved the flexibility and capacity to meet many science needs.

F. The Future Role of the Space Station in Space Science

Throughout these hearings witnesses characterized strong relationships between the future of the space sciences and the role of the Space Station. Although the witnesses differed in their assessments of the science value of the Space Station, all agreed that science objectives should be a major design and planning criteria.

Dr. Hinners summarized his view as follows:

> "There are experiments in astronomy, space physics, which require large structures, large antennas, long observing time. To use the Shuttle and Space Station to help us maintain and repair satellites has got to be a cost-beneficial way of operating in the next decade.
>
> A goal of astronomy is to have a set of observatories in space, not unlike some of our ground-based observatories.
>
> To do that requires, though, that our great investments in the space hardware, in essence, be protected. We've got to be able to keep these observatories going, to repair them, to maintain them, and that I see as a prime benefit of the Space Station and the continued use of the Shuttle...."

Dr. Van Allen cast the problem in a different context. He described the consequences of funding such a large program as a "zero sum game." In reference to the President's plan for the Space Station, Dr. Van Allen said:

> "...The President's accompanying assurance to NASA of only a 1 percent per year real budgetary growth implies, again, hard times for space science and applications for many more years if the planned expenditures for the Space Station proceed as presently projected...."

Dr. Hinners added that, given the inevitability of the Space Station, proper design for science missions will help negate the adverse consequences of such a zero sum game. He said:

> "...I see it as incumbent on the science community to do everything it can to influence early the design of the space station, so that, when it comes, it is something which we can use to our advantage, rather than being at the mercy of whatever the engineering community decides it is they'd like to build....
>
> The budget crunches are going to be there; there's no

> doubt. And I worry that the first thing to disappear when that comes will be the user accommodations. It is a very critical time coming, and to watch to see that it evolves into a Space Station that is something that the user will want to use come the nineties...."

In later testimony, Dr. Hoffman compared the Space Station development program with that of the Space Shuttle and argued cogently for strong science input. He described how budget limitations for the Shuttle resulted in the failure to implement several enhancements, such as extended duration capability and more powerful computing system. These enhancements, although only a small fraction of the cost of the Shuttle, would have substantially increased its science capability. He concluded by saying:

> "I just want to voice the fear that we may find ourselves getting into the same situation in the design of the Space Station. We know how critical the budget [illegible] You know, when we build the Space Station, the bulk of the money is going to go for the core Station that's given us the capability of keeping people up there for a long time, and it's the little extra bit that we should be putting in that will make the difference in how useful the Space Station turns out to be for the scientific and research purposes. And I hope that the Committee will keep that in mind when the budgetary review process comes up.. ."

This view was echoed by Dr. Krimigis who also drew a parallel with the Space Shuttle development program. He said:

> "...The experience with the Shuttle has not been good. We were not as successful in maximizing the science out of the system as original promises indicated, and we need to be very vigilant that the same experience is not repeated in the present situation. And we rely on the sympathetic ear of this Committee and its counterpart in the Senate to make sure that science is not overlooked in the process...."

Dr. Lanzerotti added to this discussion by comparing the strengths and weaknesses of a science focus for the Space Station development. He said:

> "...The Space Station can provide extraordinary opportunities for certain of the space sciences and--provide the resources for the science to proceed in parallel and provided that the scientists have a significant input, as I believe they are doing at the present time....
>
> I think it's important to recognize, however, that the Space Station, as it presently is conceived and

> as it will exist for the first few years of its life, operational life, is in one location in space."

He went on to explain what he meant by "one location in space". At the Space Station altitude the four great astronomical observatories could be well supported and some planetary science could be enabled. However, major missions calling for in situ measurements and close proximity planetary flybys would not be benefitted. In addition, in situ measurements required in the study of Sun-Earth interactions could not be made from the Space Station. Dr. Lanzerotti urged that the Space Station be undertaken with due consideration to the need to maintain balance for such planetary exploration and solar terrestrial research programs.

He said:

> "...so before we devote all of our resources to that, we have to make sure where our science priorities lie, and therein I sympathize to some extent with Dr. Van Allen's concern--that if all the resources go into the Space Station, and even some of the science that may be associated with that, the United States will lose its leadership role in many of the other sciences disciplines, including the exploration of the moons of Mars, which the Russians are setting out to do, or lose our leadership in the exploration of the outer planets or our leadership in the near-earth space."

With regard to Earth observations, however, Dr. Bretherton described a very specific science benefit of the Space Station program -- the Space Station platforms. In addition to providing an opportunity to plan instruments and data systems for continuous operation and evolution, the polar platforms will also present the opportunity for complementary and coincident remote sensing techniques to contribute to our knowledge of Earth systems. He said:

> "...The ... thing that the platforms provide is the fact that the individual instruments we need we have to integrate; we have to look at the same scene in several different wavelengths at the same time, several different viewing angles, and the reason is to reduce the ambiguity in the interpretation of measurements. It's part of the technology of the measurement process itself that you require all these looks.
>
> It's extremely difficult to do with our present sort of fragmented views. You have one satellite here; another satellite there; another satellite there. Even getting the data, let alone putting it together to look at the same scene is almost impossible.
>
> Now as soon as you take the integrated view, you dis-

> cover that on individual platforms the power and the weight goes up. And so we need to fly satellites that are basically more capable than our present generation of ones, and that's an opportunity that comes from the Space Station platforms, either as an integrated platform or as the modular technology was a derivative from the Space Station program...."

In the field of astronomy, Dr. Field commented on the benefits of the Space Station and man in space in general. He said:

> "...We believe that the presence of man in space -- will make it possible for us to operate these [four great] observatories over the long term. Without that, it would be impossible because surely there will be breakdown of instruments, a requirement for refurbishment of instruments, and replacement of expendables, and also from time to time putting new instruments at the focus of these telescopes. It makes sense to operate these using man in space. In the longer term, we look forward to the advent of the Space Station because that will also permit us to construct facilities in space."

Dr. Harwit provided a similar view. He said:

> "...As we enter the next generation of telescopes, we will have effectively a permanent presence in space. What the Space Station which the President has expressed so much interest in will be able to do for us is to provide us with refurbishment of the telescope. Instead of sending up telescopes for just one or two years as we have been able to do in the past, we will now have permanent observatories in space, and these permanent observatories are going to be quite expensive...."

Throughout the hearing several witnesses sought to define the exact operational relationship between the science community and the Space Station. This was best characterized by Dr. Hinners' testimony. In looking into the future kinds of science operations, he said:

> "...We envision in the future, not too many years from now, that using communications, the scientist can stay in his home laboratory or her home laboratory where they're used to working and comfortable, and participate directly through this concept we call telescience--a major advance in our thinking and one which we're structuring the Space Station program to adapt to....
>
> ...A principal investigator would remain in his laboratory and communicate through either a communications satellite or land lines to NASA control cen-

> ter and then up to the satellites and run his experiment from home."

Thus, it was clear from the testimony of the witnesses that the Space Station could offer very tangible benefits for science providing that the development of the Station receives adequate science input. It was also evident from other testimony that our concept of how to perform science in space is only now evolving and has not yet been fully developed on the Space Shuttle. In order to avoid the science shortcomings of the Space Shuttle it is clear that much thought must be given at an early stage to the functional elements and characteristics of the station that may maximize its sr r e return.

IV. FINDINGS AND CONCLUSIONS

The underlying objective of these hearings was to review in a broad sense future directions for the space sciences. The Subcommittee sought to draw upon past experience and successes in the space program as a guide in elucidating these directions. To the extent that the witness testimony represents a cross section of opinion in the scientific community, these hearings were of great value in assisting the Subcommittee to examine future options which may optimize our investments in space for scientific purposes.

The following discussion of findings and conclusions is based on the testimony and views expressed during the hearings.

There is a critical need to increase the number and diversity of flight opportunities for small and intermediate class payloads.

From the testimony presented, the Subcommittee concludes that the needs of the scientific community for small and intermediate payload opportunities are not now being met. Although, in principle, the opportunities provided by the Space Shuttle would appear to justify the phasing down of the sounding rocket program and other small payload programs, the Space Shuttle potential in this regard has not yet materialized. Several reasons cited for this are:

- slow development of the Spartan, Hitchhiker, and other programs
- scarcity of space alloted to these payloads
- inadequate crew-time availability
- lack of funding for projects which would fall into this class
- difficulty in developing man-rated equipment at low cost.

The Subcommittee infers from the testimony that, in addition to their educational value, frequent small and intermediate class payloads allow a greater diversity of science missions and provide for the interactive type of experimentation that is more amenable to the traditional methods of science. In addition, it is essential that the science community become proficient in designing for, planning for, and learning how to use the Space Shuttle.

<u>A mission model for science on the Space Station must be more fully developed and then applied to Station development.</u>

The significance of the Space Station to the space science community pervaded the hearing. Although some witnesses were pessimistic with regard to the ability of NASA to maintain a balanced science program during such a large developmental project, others characterized the benefits such an extension of our space transportation system would have in satellite servicing and science operations. Most witnesses expressed the view that science should be a major, if not primary, consideration during the design phase.

The Subcommittee noted certain contrasts in the characterization of the Space Station by the different panels representing their respective disciplines. With respect to the Earth sciences, for example, a very mature concept was presented for science and operational utilization of the free flying platforms. It was evident that this concept was directly attributable to the strong development of user needs by the scientists themselves. Although somewhat less mature, the merits of satellite maintenance, refurbishment, and servicing afforded by the Space Station were well characterized by the astronomy and astrophysics panel.

There was little convincing testimony, however, that a credible mission model exists for science operations aboard the manned element itself. Notwithstanding the obvious value of man-in-the-loop and the ability to perform interactive experimentation on the Space Station, the integration of this science potential into the design concept is yet in a primitive state. Inasmuch as this type of mission model would need to accommodate traditional laboratory experimentation methods as well as any new types of experimental protocol unique to the Space Station, the Subcommittee believes that the future of the space sciences would be well served by a greater emphasis on solving this problem.

What must evolve over the next decade is not so much the Space Station hardware and associated technologies but our science utilization concept. NASA must take steps to patricipate in and plan this evolution. From the testimony presented, a key factor in this evolution is the availability of flight opportunities on scales consistent with the intended utilization of the manned element. That is, a balanced program including not only Spacelab class operations, but also small and intermediate class payloads must be developed.

A major step which might alleviate the current deficiency in flight opportunities is the development of an extended duration orbiter capability. Past experience with Spacelab missions have demonstrated that the addition of several days on orbit would have a substantial amplifying effect on the time available to perform science operations and repair malfunctioning instruments. The Subcommittee believes that such extended duration may also facilitate man-in-the-loop interaction with lower priority small and intermediate class payloads that would not normally receive crew attention due to tight mission timelines and scheduling.

In summary, the Subcommittee finds that the future of space science operations associated with the Space Station will depend on the ability and commitment of NASA and the science community to evolve a science mission model that is responsive to a broad class of users. Key to understanding this mission model is the existing space transportation system and its optimization with respect to small users and extended mission duration.

We should examine the reestablishment of scientific cooperative agreements with the Soviet Union.

From the viewpoint of the science community, the preponderance of testimony in these hearings clearly characterized closer cooperation with the Soviets as beneficial for the following reasons:

- It reduces the cost of major missions.
- It enhances the science return.
- It can promote our international leadership role.
- It allows us to formulate our priorities with a fuller knowledge of potentially competitive programs by the Soviets.
- It may contribute to greater political stability.

The achievement of these benefits, however, depends to a great extent on how cooperative agreements are formulated and implemented. It was evident from the scientists' perspective that scientist-to-scientist exchange should be the focal point of any such agreement. In this regard, the lack of a formal agreement has had a definite negative impact on the level of scientist-to-scientist exchange. Such exchange was characterized as a learning process which should preceed any major programmatic commitments. Thus, if scientific cooperative agreements were to be reestablished, the process should begin with moderate missions and, only when the relationship is firmly established, should major missions be undertaken.

It is significant that no witnesses suggested any near-term joint manned missions. Although this may represent the witnesses backgrounds in the pure sciences (rather than in engineering) it nevertheless suggests that the technical, administrative, and political interfaces are substantially easier with joint, unmanned, science-based objectives.

The essential question implicit in these hearings, what should guide our future directions in space science, appears from the perspective of the scientists to have a strong relationship to the need to build a working and productive relationship with the Soviet Union. It should be stressed, however, that these hearings were held in the very narrow context of science considerations only. The Subcommittee is fully cognizant of the broader political considerations which should properly be the framework of any such international agreements.

In summary, the Subcommittee concludes that a renewal of cooperative agreements with the Soviet Union has the potential of scientific benefits and should be an integral part of our long range plans in space. The desirability of these science benefits in the broader context of our international relations and world leadership position should guide our future negotiations in this area.

Space activities should be an integral part of a systematic study to understand global change.

In holding these hearings, the Subcommittee was cognizant of efforts underway in the scientific community to establish closer international, interagency and interdisciplinary coordination in the study of Earth systems. An abundant amount of testimony was received which explained how the Earth's biosphere, atmosphere, and lithosphere are tightly coupled and that their study requires an interdisciplinary, holistic approach. Such an approach requires the need for an administrative framework that involves closely coordinated programs among the federal agencies and the appropriate program counterparts in other countries.

The witnesses described several characteristics inherent in the various agency missions which appear to be barriers to achieving such a coordinated effort. For example the transition of programs from their experimental and developmental phase in NASA to their long term operational phase in NOAA cannot be accomplished unless specific, unifying goals are defined in common to both agencies. Also, NSF's traditional disciplinary program structure does not appear to be flexible enough to accommodate an efficient involvement in such programs. Although these problems appeared to be well understood by the witnesses, the Subcommittee received no insight into what options were available for resolving these issues. Indeed, a principal vehicle presently available for achieving the needed coordination, the International Geosphere Biosphere Program, was viewed by the witnesses as premature.

Testimony was clear, however, that such a holistic approach requires a global view which can only be obtained from space platforms. Thus a major new direction that should be taken in the space sciences is the application of remote sensing technologies to environmental and ecological problems. This involves both short-term studies and long-term monitoring.

In summary, research planning, mission design and phasing, and agency roles should be adjusted to maximize the utility of space in obtaining a large scale planetary view of global changes.

Data systems should be planned in anticipation of both experimental and operational uses.

As a key feature of the above stated objectives for Earth observing platforms, the Subcommittee received compelling testimony regarding the need for flexibility in planning such data and instrument systems to enable both experimental and operational uses. An associated issue was the need to plan the evolution of data collecting instruments so that their operational functions can be optimized. Specifically, the witnesses advocated dual-use platforms which may facilitate both research and operational instruments and data systems, and hasten the transition between the two.

In addition, the potential transition to commercial data systems was also viewed as a significant feature in future space applications, although no witnesses offered any clear concept as to how this might be planned for. Generally, however, technical interfaces that facilitate the transition from experimental to operational systems may also have benefits for commercial systems.

Finally, the Subcommittee received ample testimony that we have not fully exploited the capabilities of remote sensing data because of inadequate applications research. Indeed, for a small increment in cost, space-derived data could achieve substantially greater utilization through a more robust program in end-use processing and software applications. Some witnesses referred to the cost of commercially provided data as a potential obstacle to such a research effort. Although the cost of doing research may be greater as a result of commercialization, no witnesses demonstrated that this situation is qualitatively any different than the situation with respect to other typical consumables and hardware in research programs.

<u>In summary</u>, future technological developments in space, particularly in the area of remote sensing, must be planned with an end objective which encompasses both experimental and operational aspects and also allows for potential commercial uses.

<u>The educational value of the space sciences should be fully exploited to raise the general awareness and appreciation of science and technology</u>.

Nearly all witnesses were in agreement with respect to the value of the space sciences in inspiring new scientists to embark on careers that would sustain the health of the space program and our leadership in space. It was evident that the characteristics of the space program that witnesses associated with educational value ranged from planetaria, which have little, if any scientific value to flight opportunities for graduate students which may have moderate to great scientific value. Thus, educational value as expressed in the witnesses' testimony should be considered as a worthwhile objective on its own merit, and may or may not be identified with the actual scientific potential of a particular program.

The Subcommittee <u>concludes</u> that a specific focus should be placed on the educational value of the space sciences. Structured ties to educational institutions at all levels should be cultivated as well as utilization of other means for directly reaching the public.

Long range discipline strategies must be developed and followed.

Many witnesses, not unexpectedly, advocated a higher level of mission activity in their particular disciplines. In some cases these arguments were supported by long range plans which establish a sequence of missions to sustain steady progress and a continuity in the level of support for these disciplines. These long range strategies are of great value, not only from a scientific standpoint, but also as a resource management tool.

It is clear, however, that the "zero sum game" that will likely dominate future funding in the space and Earth sciences will pose a major challenge to merging priorities from different disciplines. The Subcommittee believes that it is the responsibility of both the science community and NASA to address this problem.

It is incumbent on the science community to develop discipline strategies that can be carried out within the funding limitations that are likely to be in effect. To increase their chance of implementation these strategies should be planned such that no major infusion of funds should be required to accommodate new starts. That is, a new start in a particular discipline would be accompanied by decreases in other areas of that same discipline.

It is incumbent on NASA to adhere to these mission strategies to the extent practicable. This does not mean that NASA's management prerogative should in any way be diminished. Indeed, NASA should exercise leadership and take an active role with the science community in developing these mission strategies. However, once in place, it is essential to use such strategies for their intended purpose. Stop-start funding, unreliable program planning, and intermittent lapses in mission activity will have profound consequences for the research community. The very nature of the research community which makes up our technical base makes it vulnerable to such instabilities. Young researchers, in choosing their particular fields, must be assured of long-term support such that a reasonable degree of career growth can be expected. In addition, active research teams in industry and the university community need a constant level of support in order to sustain their productivity. Once such teams are disbanded due to inadequate mission activity they cannot be easily re-established.

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