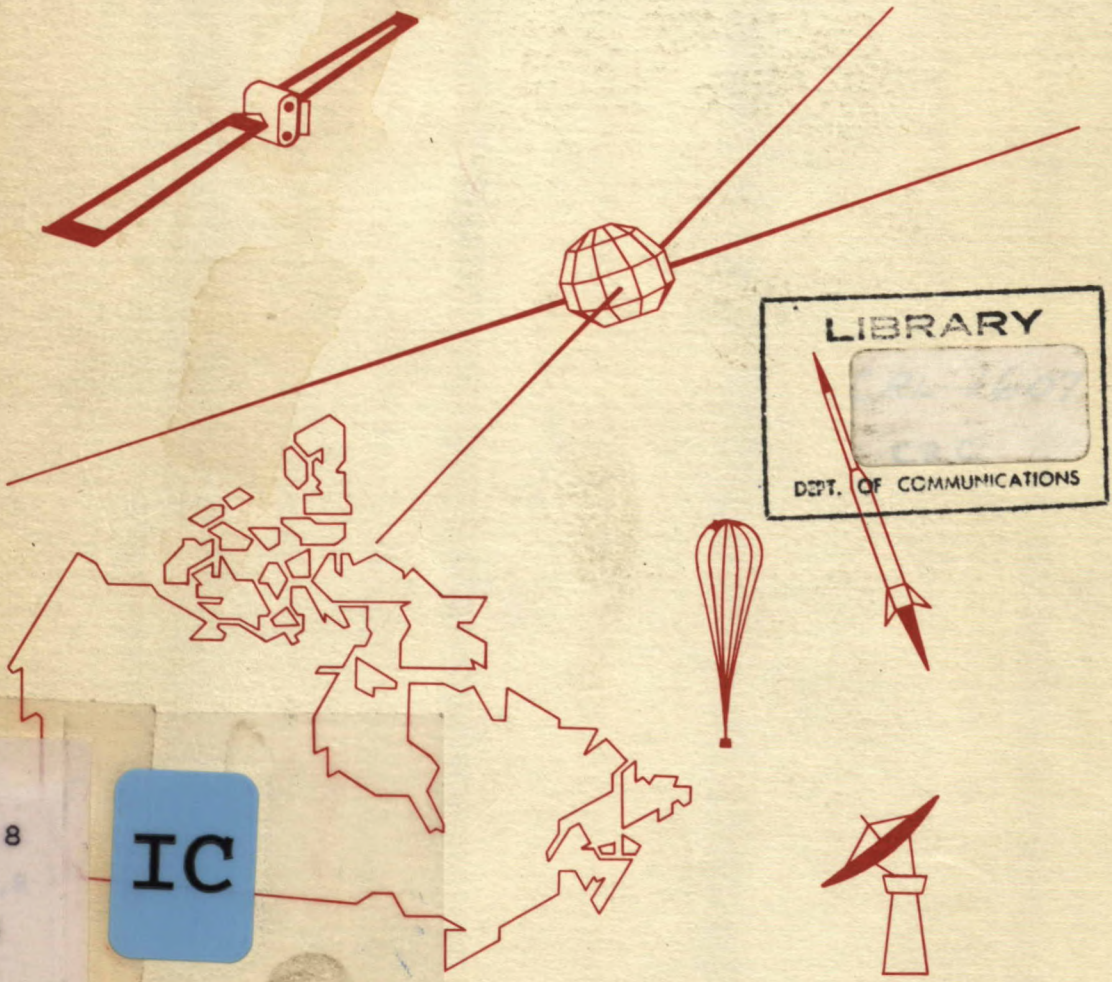
CANADIAN RESEARCH OPPORTUNITIES IN SPACE

P.A. Forsyth



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A Report Prepared for the Associate Committee on Space Research

Letter of Transmittal

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Dr. W.G. Schneider
President
National Research Council

Dear Dr. Schneider,

At its twenty-first meeting the Associate Committee on Space Research unanimously passed the following motion:

> "Moved that the Associate Committee on Space Research accept in principle the draft report "Canadian Research Opportunities in Space" by P.A. Forsyth and that a sub-committee of the Associate Committee on Space Research be established to review and revise the draft report in the light of comments of the members of the Associate Committee on Space Research and to prepare a final report for submissions to the National Research Council."

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The draft report was put into its final form on the 16th of December 1975 at a meeting held in Ottawa under the chairmanship of Mr. J.F. Aitken. Dr. Bachinsky, Dr. Barrington, Dr. Burrows, Dr. Forsyth, Dr. Hartz, Mr. Hussain, Dr. McEwen and Dr. Shepherd were present at the meeting.

The essence of the report is that highest priority be accorded to the establishment of an Office of Space Research for the purpose of planning, coordinating and providing leadership for space research in Canada. The priority task of this office is to plan and coordinate a balanced program encompassing satellites, rockets, balloons and ground based observations. To achieve this balance it is vital that a scientific satellite program be re-established. This goal should be achieved without sacrificing the existing space research activities. The report outlines the necessity for modification and extension of rocket, balloon and ground based activities to achieve an effective national program in space research.

...2

Box 11490 - Station H
Ottawa K2H 8S2

The policy of the government in the field of space research as stated on 16 July 1974 by the Honourable Jeanne Sauvé, the then Minister of State for Science and Technology, is as follows: "Basic to all activities in this field is the appropriate knowledge of space science and technology. To be aware of new applications for space systems, we must understand the nature of space and the technology of space systems." The report describes programs and projects that will achieve the stated policy of the government in an effective manner. It also sets out a plan for the effective use of manpower and material resources by government, university and industrial sectors.

The recommendations of the report are compatible with the objectives of the National Research Council in tackling long term problems of national concern, providing assistance to industry, creating new knowledge and supporting national facilities. For this reason it would be highly desirable that the proposed Office of Space Research be established within the National Research Council.

In submitting this report the Associate Committee on Space Research hopes that the review of the aspirations of the Canadian Space Science community that it contains, and the recommendations on organization and programs will be a valuable aid to council in reviewing NRC's part in Canada's space research activities.

Yours truly,

R. E. Barrington

R.E. Barrington
Chairman,
Associate Committee on Space Research

CANADIAN RESEARCH OPPORTUNITIES IN SPACE

A survey of possible future directions
for space research in Canada

Prepared for the
Associate Committee on Space Research
of the
National Research Council

By

P.A. Forsyth

Assisted by: T.R. Hartz
D.J. McEwen
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Steering Committee: J.F. Aitken
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November 1975

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"Basic to all activities in this field is the appropriate knowledge of space science and technology. To be aware of new applications for space systems, we must understand the nature of space and the technology of space systems."

The Honourable Jeanne Sauvé
Minister of State for
Science and Technology
July 16, 1974.

Acknowledgements

As the "principal author" of this report I was fortunate indeed to work with a Steering Committee made up of dedicated individuals. Each member gave generously of his time not only to the meetings but to the careful and thoughtful criticism of each section of the report as it was completed in first draft. I also owe much to the willing sacrifices made by the colleagues who accompanied me on the visits and later made objective and perceptive summaries of the discussions. The names of these people appear on the title page. Others who contributed generously to the report include C.D. Doucet, N. Hussain and J.A. Tarzwell of the National Research Council and D. Martin, M. Meighen and I.P. Sinclair of the University of Western Ontario. But there is no room here to include the names of the host of others, including both established scientists and graduate students, who undertook specific tasks or gave up valuable time to detailed discussions. I hope that the names of all of them appear in Appendix II and I regret that it was not possible to include in the report all the ideas and suggestions that were offered. To all those who contributed to the study, whether or not their thoughts appear explicitly in the report, I offer my sincere thanks for, whatever the fate of the report may be, they have convinced me of the existence of a vital cooperative spirit within the space research community in Canada which augurs well for its future.

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The Future of Aeronomy and Space Physics in Canada (December 1975) prepared by the Division of Aeronomy and Space Physics of the Canadian Association of Physicists - A. Vallance Jones, Editor.

Part A

Summary of the Report

This study was undertaken as a result of the growing concern among the Canadian space science community about the rapid deterioration of Canada's position in space research. Only a few years ago Canada occupied a leading place in space research but other nations, including some who have a less obvious stake in the exploitation of space, have overtaken and are forging ahead of Canada. The situation is not irretrievable but certainly we are at the crossroads and immediate action is necessary. If no action is taken Canada will lose the initiative in space research and with it many opportunities to use space for the management of the nation's resources, its land, its oceans and for the benefit of its industries and its people.

Faced with this crisis the study has sought to find out what space research should be done and the resources in money, people and time required to accomplish that research. The study attempts to cover all significant areas of space research including Aeronomy and Space Physics, Meteorology, Remote-Sensing, Space Astronomy, the Life Sciences, and Space Processing. To do this, opinions and advice were sought from a large number of people either through interviews or by written submissions. Several groups and individuals undertook to contribute carefully reasoned examinations of particular areas and concrete suggestions for the future. Most of the larger groups in government, industry and the universities involved in space research were visited and what emerges is not only a consensus but a remarkable degree of unanimity among these people, all of whom perceive the present situation to be due largely to the lack of a comprehensive, coherent, balanced plan for the conduct of space research in Canada. The details of visits, interviews and briefs received are given in Appendix II.

To be successful a program for space research must concentrate on carefully chosen objectives and be carefully monitored and managed. The nature of the program and the objectives must be determined within the constraints of available funds and available

manpower. Some legitimate objectives in the utilization of space will not be reached unless an increase in research expenditures is made, but given a suitable reorganization of the activity the amount of the increase is not large.

The general outline of a suitable space research program for Canada is given in the body of the report. The final program plan should conform to certain principles, namely:

> It should concentrate on Canadian needs, including those related to sovereignty over Canadian lands and contiguous oceans, to quality of Canadian life, to well-being of Canadian commerce and to national credibility.
>
> It should concentrate on phenomena that are best studied in Canada.
>
> It should exploit existing Canadian expertise.
>
> It should benefit Canadian industry.
>
> It should be capable of bringing international recognition to Canadian science.
>
> It should provide efficient, continuous utilization of available resources (both human and financial) in government laboratories, in universities and in industry.

The report argues that, particularly in space science, a program incorporating these principles is entirely possible, that the present time is appropriate to launch the program, and that the majority of the space researchers in Canada are anxious to cooperate in carrying out the program.

Recommendations

The report makes one major recommendation. This recommendation which represents the central conclusion of the study, has to do with an organizational change that is necessary if meaningful planning is to be introduced into the scientific sector of space activities in Canada. The discussion relating to the recommendation will be found in the section entitled "Organization" starting on p. 61. To summarise that discussion here - at the present time there is no single agency in Canada responsible for planning, coordinating and leading the overall program of scientific research in space. In the context of this report "space research" is intended to encompass the scientific activities related to space.

Major Recommendation

M1 That an agency of Government, such as the National Research Council, be designated the lead agency for space research and that it set up an Office of Space Research. The director of the Office should be a member of the Interdepartmental Committee on Space. The Office should have the following specific responsibilities:

a) Initially to draw up, in consultation with the various sectors, a five-year program with projections to ten years for space research activity in Canada, and to revise the five-year plan and the ten-year projections annually. In drawing up the plan the Office of Space Research should examine, evaluate and set priorities on the detailed recommendations of this report with a view to incorporating, on an appropriate time scale, those that retain their significance in the light of changing national and international conditions.

b) To invite the universities with significant involvement in space research to form an incorporated association to plan, propose and manage space research in the university sector.

c) To receive and assess proposals from the association of universities, to arrange funding and to supervise the carrying out of the approved research program by the association of universities

d) To arrange for the availability of all those facilities for space research which are used by a number of research groups. This should include specifically, rockets, balloons, scientific satellites, campaign stations and data platforms used for research purposes. In carrying out this responsibility the Office of Space Research should draw upon existing capabilities in government laboratories, in industry and in universities, and make provision for those facilities where there is no existing capability.

e) To seek the cooperation of the appropriate government agencies in carrying out the research plan both through the Interdepartmental Committee on Space, and through direct bilateral arrangements with government laboratories.

f) To incorporate into the overall program reasonable mechanisms by which Canadian groups can participate in international undertakings in space research. This should include involvement in the definition of international missions, funding of conceptual design and feasibility studies, and commitment to fund those proposals that finally are accepted.

g) To arrange for the efficient use of all available manpower and funds in achieving the program objectives, and to take the initiative in seeking new resources where these are required to meet the needs of the program. (See also detailed recommendations 01, 02 and 03.)

(see p. 65)

Politics - not action!

Detailed Recommendations

Although the implementation of the Major Recommendation for the establishment of an Office of Space Research is essential to the well-being of space activity in Canada, the report also makes a number of detailed recommendations. Since part of the Major Recommendation is that the Office of Space Research should further examine and evaluate the detailed recommendations, the list of detailed recommendations cannot be regarded as definitive. They represent collectively one form of a suitable research plan as perceived by the space community during the summer of 1975. The significance and importance of at least some of the detailed recommendations will change with time and for that reason the implementation of each of them and of each of the new proposals which, though not included in the report, may arise in the future, should be the subject of continuing adjudication by the Office of Space Research. In each case the discussion relating to a particular recommendation may be found by means of the page reference which follows the recommendation. Some of the financial implications of these recommendations are discussed in Appendix I.

Organizational Recommendations

In the Major Recommendation it was appropriate to outline the duties of the Office of Space Research in broad terms. While that outline is inclusive it is also appropriate to make more detailed recommendations in certain areas where specific action by the OSR is desirable.

01 That the Office of Space Research collaborate with the appropriate agencies in finding means by which a sufficient number of younger scientists can be brought into the space research program, offered reasonable career prospects and given the opportunity to progress to positions of research leadership. (p.75)

O2 That the Office of Space Research, through its direct liaison mechanism with individual government departments, take the initiative in arranging interdepartmental transfers of funds and manpower to concentrate the most appropriate research expertise on the achievement of each research objective. All such transfer arrangements should protect reasonable career aspirations for the scientists involved. (p.76)

O3 That the Office of Space Research institute a procedure by which it and other government agencies can respond to industrial proposals for space experiments. The objective of the procedure is to enable industrial employees to carry out space experiments under contract. (p.79)

Recommendations for facilities

A number of existing facilities should be changed or expanded and some new facilities are needed in order to carry out the coordinated program discussed in Part B. These facilities are covered in the following detailed recommendations.

F1 a) That a sequence of small scientific satellites be instrumented to study the magnetosphere and magnetosphere-ionosphere-stratosphere interactions in the total program of space research. If planning were started now the first satellite could be in orbit by 1979 or 1980 but the timing should be such as to ensure continuity of activity by all sectors. (p.21)

b) That early consideration be given to placing an experimental satellite in a 12-hour elliptical orbit at an inclination of about 60°, or a 24-hour elliptical orbit of lower inclination, to investigate both the space environment of the orbit and its utility for remote-sensing and other applications. (p.58)

F2 That three campaign stations — one at the latitude of the daytime polar cleft — one in the auroral zone — and one a few degrees south of the auroral zone be designated and equipped for studies of magnetosphere-ionosphere-stratosphere interactions. The two northern stations should have rocket launching capability and all three stations should have balloon launching capability and good data communication links to provide access to real-time data from at least 12 remote data platforms. (p.24)

F3 That at least twelve stations in any comprehensive array of data platforms of the kind suggested in Recommendation S5 be instrumented for ground-based measurements pertinent to the space research program. (p.25)

F4 That three transportable balloon launching facilities (of which one should be capable of handling the very large balloons) be made available for use at a variety of sites in Canada including the campaign stations. (p.27)

Program recommendations

The following program recommendations serve to indicate the scope and balance of a desirable program.

National program recommendations:

NP1 That provision be made for the planning and funding of two campaigns per year for study of magnetosphere-ionosphere-stratosphere interactions. (p.20)

NP2 That the potential for atmospheric constituent measurements using lasers of new satellites like the Lageos satellite be exploited, and that a retro-reflector be included on some future Canadian satellite in geostationary orbit. (p.22)

NP3 a) That approximately nine large and ten small rockets per year be made available to the space research program. (p.24)

b) That in order to permit Canadian astronomers to make realistic proposals for space experiments in international programs the evaluation and funding of the necessary preliminary rocket experiments be initiated. (p.45)

NP4 a) That the Office of Space Research be responsible for determining the total number and types of balloons needed in the Canadian program and for coordinating the use of the balloons. (p.27)

b) That in order to permit Canadian astronomers to make realistic proposals for space experiments in international programs the evaluation and funding of the necessary preliminary balloon experiments be initiated. (p.45)

c) That the needs of the cosmic ray researchers for balloon flights be considered in formulating the plan for an integrated program of balloon flights in Canada. (p.50)

NP5 That while the studies now being carried out by the Atmospheric Environment Service into the utilization of presently available remotely-sensed data for computer-based weather forecasts should be continued and expanded if possible, some research effort should be directed toward discovering space-related techniques for acquiring new measurements that are likely to improve the accuracy of weather forecasting. (p.35)

NP6 That the present program of measurements relating to atmospheric constituents within AES should be expanded and coordinated with other research agencies with a view to developing a comprehensive, long-range Canadian service for monitoring of the atmospheric pollutants. (p.36)

NP7 That in support of remote-sensing research the universities be encouraged to initiate the necessary training in science for potential users of remotely sensed data. (p.39)

NP8 That a specific plan, including timetable, be developed for remote-sensing research and sensor development to ensure that Canada shall have within, say, ten years, an adequate capability in satellite remote-sensing of our land-based resources and in all-weather ice and ship surveillance of the neighbouring oceans. (p.41)

International program recommendations:

IP1 That the nature and extent of Canadian involvement in the scientific component of the shuttle program be defined by the Office of Space Research and that consideration be given to further Canadian contributions of hardware to the AMPS shuttle configuration or to later configurations in the series. (p.33)

IP2 That the Office of Space Research seek bilateral agreements which would provide interested Canadian space astronomers with an appropriate amount of observing time on space telescopes including both shuttle-mounted telescopes and shuttle-launched space telescopes. (p.45)

IP3 That in collaboration with the Medical Research Council assistance by means of bilateral agreements be given to medical scientists to permit them to participate in space experiments including the shuttle-borne experiments. (p.47)

Study recommendations

In the present study a number of questions were reaised that could not be resolved in the form of firm recommendations. These should be pursued by new, specific studies initiated by the Office of Space Research in order that a definitive position can be achieved on each question.

S1 That a study be undertaken to determine the preferred technique for and extent of a Canadian network of stations to measure atmospheric motions in the 75 - 100 km height range. (p.29)

S2 That the national biological associations in Canada be invited to study the new research opportunities provided by the present and future generations of remote-sensing satellites with a view to stimulating active participation of biologists in the refinement of remote-sensing techniques for biological research. (p.48)

S3 That an appropriate NRC committee should institute an early review of the present support of cosmic ray research in Canada, particularly with reference to the superneutron monitor network. The objective of the review should be a decision either to support the monitor network over several years or to phase out the network. (p.50)

S4 That the degree of interest in space processing within Canada be assessed to see if a series of rocket flights devoted to space processing is justified. Such rocket experiments would be preliminary to submission of Canadian experiments to the shuttle program. (p.52)

S5 That the need for scientific data acquisition from remote platforms be evaluated in relation to the total Canadian requirement for data platforms with a view to either adopting an existing system, such as the ARGOS system, or starting a research and development program aimed at producing a more suitable data platform system for Canada. If the decision is to adopt an existing system, consideration should still be given to undertaking a research and development program involving all sectors and directed toward all aspects of automatic stations including sensors, data storage and format devices, and environmental protection. (p.55)

S6 That a new evaluation be made of gun-launching techniques for those research applications in which a payload is to be lifted to a height of about 100 km and where economy is important (as in synoptic studies). (p.60)

Part B

Introduction

This paper discusses the future of space research in Canada. For our purposes space research can simply, and perhaps loosely, be defined as research *on* space, research *from* space and research *in* space. Canada has substantial experience in the first of these—research on the space environment; is rapidly gaining experience in the second—research on remote-sensing of the earth and on observation of astronomical objects beyond the earth's environment; but has only very limited experience with the third—research, such as that on space processing, which depends on the unique physical conditions provided by space vehicles.

In discussing space research it is difficult to characterize and separate the different areas of activity in order to discuss them in a simple logical sequence. This is because one area may involve several *disciplines*, two or more *sectors* and several *facilities* and another area may involve several of these same *disciplines*, *sectors* and *facilities* in a different mix. In the present context, *discipline* is used in the traditional sense of an academic subject area such as aeronomy or meteorology; *sector* is used to indicate one of the three divisions of the community, that is, government, industry or university; and *facility* indicates an identifiable equipment or collection of equipments needed to carry out a particular research. In spite of these obvious difficulties the course chosen in what follows is to describe an overall program of research, starting from the more developed areas and progressing to the less well developed. In all areas, recommendations are made regarding at least the general direction that should be followed to provide a coherent overall program of research which is likely to be of maximum benefit to all three sectors. In some cases alternatives are pointed out. In fact, other alternatives exist and many will occur to the reader. The ultimate choice between the alternatives must involve a judicious assessment of the various arguments relating to that choice and it cannot be claimed that this has or could have been done in the time available for the present study. What is important is that

the course chosen for each area should be compatible with an overall program which encompasses all areas.

The substantial past accomplishments of Canadian space research are well known and will not be enumerated here. Nevertheless, any review of space research over the last few years leads inevitably to a conclusion that can be summarized in the following three statements:

1. The quality of Canadian space research has been high.

2. The effectiveness of Canadian space research has not been as great as it could have been because of fragmentation and lack of balance. Consequently Canada's place in the international community of space science is rapidly deteriorating.

3. The lack of effectiveness is no-one's fault.

Indeed, it is no-one's fault because no single person or agency has been given the responsibility for formulating and guiding a comprehensive, balanced program of research that would both keep Canadian research near the forefront of knowledge and at the same time be responsive to Canadian needs. A central theme in what follows is the proposed organization of Canadian space research into a program aimed at the solution of well-defined problems. This is a substantial departure from past practice. It has been usual for each agency or group or, sometimes, each individual to pursue an independent research objective. It is clear that this approach is no longer appropriate. Space research has become sophisticated and complex and requires the cooperative efforts of many people in order to achieve meaningful progress. Even the largest groups, such as those in government laboratories, cannot mount an adequate attack on some of the more significant problems. It is only through the concerted efforts of most of the space research community in Canada that we can hope to bring Canadian research back to the forefront of international science. It is encouraging to note that the space research community in Canada

does not require persuasion on this point. The majority, including nearly all of the leading researchers, are eager to participate in a comprehensive program and are quite willing to accept the necessary discipline implied by such a program even to the extent of re-directing their individual researches toward common goals. The prosecution of such a comprehensive program will require new techniques of coordination and management but we will need to learn those new techniques if we are to exploit the opportunities and capabilities that exist in Canada.

With this in mind we turn to a discussion of the role of space research in the Canadian context.

Why Space Research?

The activity now designated as "space research" encompasses many areas of investigation that predated the use of the term. One such area is the investigation of phenomena of the high atmosphere. Possibly the earliest serious studies of these phenomena were directed toward understanding of aurora, motivated by the difficulties encountered in northern navigation due to disturbances of the earth's magnetic field[1]. In the early years of the last century it was realized that Canadian territory was the focal point of important natural phenomena which for very practical reasons needed systematic study. Since there was at that time no indigenous mature scientific community it was inevitable that the necessary investigations were carried out by expeditions from the old world. Again, and for the same reasons, during the first International Polar Year 1882-83 Canada was the focal point of much foreign-based research related to geomagnetic and auroral phenomena. By the time of the second International Polar Year, 1932-33, Canadian science was sufficiently advanced to make some contribution to the study of those phenomena which are best studied from Canadian territory. But for more than a century real understanding of the auroral process eluded both the visiting and the Canadian scientists. Finally, in the years following the second World War new techniques appeared which revolutionized auroral studies and Canadian scientists were for the first time in the forefront of the research, although many of the most important contributions were still being made by American and European scientists. Nevertheless, under the stimuli of an expanding research area, real competition with some of the world's leading scientists and the chance to study uniquely "Canadian" phenomena, the space research community in Canada rapidly gained in maturity and international recognition. Today, although much is still not known, the knowledge of auroral disturbances is many fold greater than it was thirty years ago.

Much of the advantage gained by Canadian space researchers over those years has now been dissipated, but new horizons are

opening and new opportunities are presenting themselves, which, if seized, could lead Canadian science once again to the front rank in a uniquely Canadian area of research. The focus of interest has shifted to the complex mechanisms whereby energy is transferred from the solar wind through the magnetosphere and ionosphere into the lower reaches of the atmosphere. Important clues to the dynamical processes in the magnetosphere are to be gained by studies carried out inside the polar cap and in the region of the daytime cleft, and once again nature has ordained that the important observations must be made from points on or above Canadian territory. But even with this advantage it is not sufficient to encourage Canadian scientists (by increased funding) to work in these areas. It is important that Canadian space researchers be organized, or organize themselves, in such a manner as to permit a concerted attack on a limited range of problems. Only by this means will an acceptable rate of progress be achieved and failing that the necessary research will still be done but not by Canadian scientists. As an enlightened nation, Canada could not conceivably bar its territory to scientists of other nations who come to solve problems that are being tackled inadequately by Canadians even when this means opening the most sensitive regions of the northern archipelago to foreign expeditions. And more important than any consideration of territorial sovereignty, the scientific information gained may once again prove to be of economic or social importance. But more important than either of these considerations is the simple fact that national pride would be greatly damaged if Canadian science were seen to be unable to answer the challenge provided by a new and uniquely Canadian natural phenomenon.

It is often difficult to justify the need to understand newly discovered natural phenomena because the applications of new knowledge seldom emerge before the knowledge is acquired. That this difficulty should not be permitted to strangle research is amply illustrated by very recent experience with communication satellites in geosynchronous orbits. Several satellites have

exhibited "anomalous behaviour" at times of geomagnetic disturbances. In at least one case and possibly two the same phenomenon appears to have caused catastrophic failure of the spacecraft. Unfortunately, the present knowledge of the space environment is not yet sufficient to indicate unequivocably the remedial action necessary, but it is sufficient to suggest the direction in which research should go. It seems likely that the immediate cause of the switching and control anomalies is differential spacecraft charging caused by unexpected and as yet unassessed factors in the space environment. Obviously, it is very important to learn quickly how this spacecraft charging comes about and how it can be prevented.

Another new area, not unrelated to the dynamics of the magnetosphere, is being uncovered. This relates to the interaction between the highest and lowest levels of the atmosphere, between the solar wind and weather. Only enough is now known to see that this is going to be an important and rewarding area of research in the coming years. While not uniquely Canadian the area is important to Canada and should be part of a comprehensive space research program.

Anyone who has climbed a hill to get a better view of the surrounding country is already aware of the basic advantage of remote-sensing. The larger the area to be surveyed and the more difficult the terrain, the greater is the advantage of remote-sensing. In the words of one of the people interviewed for this study, "Canada is almost designed for remote-sensing"[2]. In another way, too, Canada has a special interest in remote-sensing. The Canadian economy is heavily dependent upon renewable and non-renewable resources. The intelligent management of resources requires information. On the scale required, the necessary information can probably be better supplied through satellite remote-sensing than by any other means. To exploit the full potential of this new technique will require a substantial research effort. Judged by comparison with the rate of application of other new technology in Canada the progress in remote-sensing

has been rapid, but judged on the international scale where, for example, a small country like Japan invests many times as much money in remote-sensing research as does Canada who has a much clearer and more obvious need, it can only be said that Canada's progress is dangerously slow. Dangerous, because in this area the information is particularly sensitive. It is not only national prestige that is at stake. The information derivable from remote-sensing gives economic and political advantage to those who possess it.

Canada has a large territory. The exercise of sovereignty over this vast land area and the contiguous oceans carries with it clear responsibilities to other nations. One of these is the responsibility for monitoring the environment with a view to correcting local deterioration or cooperating with other countries to reverse deterioration of the environment on a global scale. Because of the significant fraction of the earth's surface under Canadian jurisdiction it behooves us to develop efficient methods of monitoring environmental factors. Space technology already has been shown to provide a significant part of the needed capability and shows promise of providing much more.

Space research requires sophisticated technology, and it has already been demonstrated that where that technology is permitted to grow in industry in response to a domestic need it can lead to a substantial export market. However, in the so-called "high technology" market, what is really for sale is specialized knowledge and that knowledge must be continuously renewed in order to remain competitive. A comprehensive long term program of space research leading in an orderly way to space applications would undoubtedly stimulate the expansion of existing industry and create new industries. The present difficulty experienced by high technology firms is only partly due to the level of funding. It is much more directly due to the intermittent nature of the funding. The assembly of a competent development team cannot be accomplished quickly and its dissolution leaves long-lasting scars in the technological community. The aerospace industry has made an

eloquent case for continuity of funding of major projects in order efficiently to use the technological capability that exists in Canada[3]. An adequate program plan to accomplish this would necessarily extend over more than the research activity to include space applications as well. Nevertheless the industrial implications of a research program should be integrated into the larger program of space activity. A well-planned program of space activity could provide the continuity of domestic sales which must be the foundation of export sales.

While emphasizing the national objectives of a Canadian space program it must be remembered that science is inherently an international activity. Canada can do only a small part of the total research in any field and this certainly is true of space research. At the same time Canada's people, its industries and its governmental agencies need quick access to all new scientific knowledge as it is generated. The most efficient way for Canada to maintain quick access to this new knowledge is to have a significant number of scientists engaged in productive research and thereby contributing to the total pool of new knowledge.

The need to emphasize space activity in Canada has already been recognized by the government. In her statement of 16 July 1974, The Honourable Jeanne Sauvé, then Minister of State for Science and Technology, outlined the unique importance attached to space by the government, and went on to point out (in the passage quoted as a frontispiece to this report) that to maintain space activity we must understand the nature of space. To do this we must carry out research *on* space, research *in* space and research *from* space.

In summary Canada should do space research:

— because some of the problems are uniquely associated with Canadian territory;

— because these problems are ripe for solution;

— because Canada has the capability to do front-rank research in solving these problems;

— because Canada needs better quality weather forecasts and can expect to achieve them through space activity;

— because Canada needs new, more efficient means of managing its natural resources;

— because Canada needs remote-sensing to monitor its environmental characteristics efficiently and for a variety of other purposes;

— because Canadian industry will benefit from a program of space activity provided that activity is incorporated into a logical comprehensive program;

— because Canada needs access to international space science and can gain that access by contributing knowledge obtained from a Canadian-based selective research program of high quality.

— because Canada is committed to a continuing program for the utilization of space in the interests of the nation, and that program needs research to guide it.

Against that background it is worthwhile to look at the nature of the various components of a desirable and achievable research program.

Aeronomy and Space Physics

The program concept

One person interviewed for this study said in effect "We study the oceans because we use them, we should do no less for space"[4]. This is a valid parallel but just as the totality of research on the oceans is beyond the capability of any nation, so is the totality of research on space. Canada must be selective in its approach. The Division of Aeronomy and Space Physics (DASP) of the Canadian Association of Physicists has addressed itself to this problem and produced a paper recommending a program of research which includes a concentrated attack, both on selected problems of space physics, and on aeronomical and dynamical problems associated with levels of the atmosphere down to and including the stratosphere. The DASP paper is reproduced as a companion document. It makes the case, both for the choice of research area and the structure of the program in much greater detail than can be done here, but certain aspects of the DASP paper deserve further comment. This discussion is intended partly to draw attention to certain key elements of the DASP paper and partly to extend the discussion in the light of new information which was not available at the time that paper was written. In the course of visiting the universities and government laboratories for the present study most of the central elements of the program proposed by DASP were discussed and there seems to be a strong majority support for the concepts used in the DASP paper.

For reasons similar to those already outlined the DASP paper recommends that the research on space be concentrated on the various aspects of a single all-encompassing "general problem". It is stated as:

> How is solar energy transferred to the earth's atmosphere, both to the magnetosphere by the solar wind and by direct radiation to all levels of the atmosphere?

This is taken to include:

(a) the overall structure and dynamics of the magnetosphere

including magnetospheric substorms,

(b) the reaction of the neutral atmosphere to the deposition of electromagnetic radiation and energy by solar particles,

(c) the coupling of the magnetosphere with the neutral atmosphere via the ionosphere,

and the paper then goes on to give a long list of examples of specific problems that could be tackled as part of work on the theme as stated above.

Recognizing the limitations of personnel and funding, the DASP paper recommends the use of a campaign approach for at least the high latitude component of the research program. What is suggested is that observational campaigns each of one to three weeks duration should be organized around quite specific objectives, chosen well in advance, so that members of the space research community can plan their participation and cooperation to gain maximum benefit from each campaign. This campaign approach seems entirely appropriate to the scale of Canadian effort and is heartily endorsed. *It is recommended:*

NP1 *That provision be made for the planning and funding of two campaigns per year for study of magnetosphere-ionosphere-stratosphere interactions.*

The facilities

The facilities required for the aeronomy and space physics activities are as follows:

Satellites:

Much of the early success of Canada's space research activity derived from the use of scientific satellites in the Alouette-ISIS series. There are now no concrete plans to make scientific satellites available in the future. Without further scientific satellites the Canadian program will be deprived of a crucial element — the ability to make measurements in the very regions that are being investigated. Clearly, a sequence of scientific satellites

is required. Specific examples of the satellite missions that would be of value to aeronomy and space physics, as outlined and justified at greater length in the DASP paper, are included in what follows. These are not given as specific recommendations but rather as illustrations of the kinds of satellite missions that would be appropriate. Space research using satellites is, on the world scene, a rapidly developing and rapidly changing activity. The maximum rate at which Canadian satellites are likely to be added is still so slow as to make it impractical to plan for a series of specific missions. Each mission must be chosen with care against the background of existing satellites and those planned by other countries. *It is recommended:*

F1 a) *That a sequence of small scientific satellites be instrumented to study the magnetosphere and magnetosphere-ionosphere-stratosphere interactions in the total program of space research. If planning were started now the first satellite could be in orbit by 1979 or 1980, but the timing should be such as to ensure continuity of activity by all sectors.*

The following missions should be considered:

(a) A Polar Cap Monitor (PCM) small scientific satellite.

This satellite having a highly elliptical, highly inclined orbit (the DASP paper suggests a 6 hr orbit but a 12 hr orbit might be preferable, see later comments on the 12 hr orbit) would be instrumented to provide two dimensional imaging of the aurora, probably in the ultraviolet, electrical and magnetic field measurements over a wide frequency range, particle measurements down to low energies, and thermal electron and ion measurements. This satellite has many advantages including the fact that it is complementary to earlier satellites and does not overlap significantly with present or planned spacecraft. It would also provide useful information even after the shuttle becomes available.

(b) An Atmospheric Composition Measurer (ACM) small scientific satellite.

This satellite in a relatively low polar orbit would concentrate on optical scanning measurements for the purpose of deriving vertical (and possibly horizontal) composition profiles from upper atmospheric emissions. It would also be instrumented for direct measurements of a kind similar to the PCM but such measurements on the ACM would be much less valuable. This satellite might well be regarded as a test platform for shuttle instrumentation.

(c) A geostationary platform

If space can be provided aboard geostationary applications satellites it could be used effectively for particle and field measurements, optical imaging and for reflectors or receivers for laser experiments.

(d) Other satellite experiments

A substantial expertise exists in Canada in the use of lasers for monitoring of atmospheric constituents. A major step forward in this work could be triggered by the availability of satellite-borne laser receivers or retroreflectors. Fortunately, the Lageos satellite will carry retroreflectors suitable for laser measurements even though it will be in a polar orbit. The use of this or similar satellites for atmospheric measurements should be encouraged. An alternative which should be seriously considered is the fitting of a retroreflector to a future Canadian applications satellite in geostationary orbit. A satellite of the Anik type would be well suited and the potential return in information about atmospheric composition would seem to justify the small cost and weight requirement. *It is recommended:*

NP2 *That the potential for atmospheric constituent measurements using lasers of new satellites like the Lageos satellite be exploited, and that a retro-reflector be included on some future Canadian satellite in geostationary orbit.*

Satellites carrying stable frequency radio beacons have proven to be valuable for a variety of ionospheric studies and promise to be even more valuable for studies relating to the polar ionosphere. The most frequently used satellites for these purposes are those in the NNSS (Transit) series. Unfortunately it is often difficult using these satellites to relate the radio propagation results to other geophysical phenomena. For this reason it is desirable to place radio beacons aboard any satellite designed to measure magnetospheric or ionospheric characteristics. The requirement is for at least two beacons on widely separated frequencies in the VHF-UHF bands and that the two frequencies be derived from a common source.

Campaign Stations:

Three campaign stations are required, one located at the latitude of the dayside polar cleft, one in the auroral zone and one somewhat to the south of the auroral zone. Although these would be permanent stations they would be manned only during campaigns. Only bulky or inexpensive equipment would be left permanently at the station. The remaining equipment necessary for each campaign would be brought in by the observational team. The two northern stations would have rocket launching capability. All three stations would have balloon launching facilities, only one of which need be capable of launching the very largest balloons. As noted below, the balloon launching facilities should be completely transportable in order that they can be used elsewhere during the interval between campaigns.

The basic instrumentation for ground based observations at the campaign station might be as follows:

— a modern ionosonde

— a magnetometer with both digital and chart recorders

— a riometer

— a scanning photometer

— electromagnetic sensors (VLF and ELF)

— an all-sky camera and/or an electronic imaging device

It is recommended:

F2 *That three campaign stations — one at the latitude of the daytime polar cleft — one in the auroral zone — and one a few degrees south of the auroral zone be designated and equipped for studies of magnetosphere-ionosphere-stratosphere interactions. The two northern stations should have rocket launching capability and all three stations should have balloon launching capability and good data communication links to provide access to real-time data from at least 12 remote data platforms.*

Rockets:

The fact that the rocket program in Canada has been seriously curtailed in recent years for lack of funds has caused widespread concern. Nevertheless if the campaign approach is adopted it does not seem likely that the present rocket program could be greatly increased without unbalancing the research program. In fact the requirement would be about three large rockets (BBV or IV) for each campaign (two campaigns per year) plus about three large rockets and ten small rockets (BBVI) to be used for initial developmental flights or other experiments outside the campaign. *It is recommended:*

NP3 a) *That approximately nine large and ten small rockets per year be made available to the space research program.*

Remote unmanned stations:

A serious deficiency in past rocket experiments has been the lack of adequate ground based measurements to provide a real-time evaluation of geophysical conditions. To overcome the deficiency it is suggested that a number of unmanned observatories be operated continuously in order to provide

a means of continuously monitoring the electromagnetic environment in the region of the campaign sites and that the data from the remote sites be made available, through an adequate communication system, in real time, to each of the three campaign stations during campaigns. A minimum of 12 sites are needed, disposed in a two-dimensional array with each station equipped with:

— a fluxgate magnetometer

— a riometer

— a photometer or electronic imaging device

It is recommended:

F3 *That at least twelve stations in any comprehensive array of data platforms of the kind suggested in recommendation S5 be instrumented for ground-based measurements pertinent to the space research program.*

Again, the development, instrumentation and operation of these twelve stations, if undertaken in isolation, would undoubtedly be too costly to be feasible. On the other hand this requirement fits well with other requirements involving a large number of remotely interrogated data platforms. As is outlined later under "Data Platforms" the pooling of all Canadian requirements may well lead to the development of an economically viable general purpose data platform which is attractive to other than Canadian users.

Balloons:

The use of balloons in Canada has been spasmodic and uncoordinated due in large measure to the lack of clear procedures by which Canadian scientists could "get aboard" balloons. There is a modest requirement for balloon flights in conjunction with the campaigns but there are substantial other requirements for balloon flights and again, if these requirements were pooled there would seem to be an adequate base for a continuing program of balloon launches. For the

campaigns the most demanding requirement has to do with the measurement of electric fields. It is not universally accepted that meaningful measurements of ionospheric electric fields can be made from balloons although there is a rapidly growing body of evidence that suggests that the measurements do contain information about the ionospheric fields[5]. The difficulty is that a great deal of noise is introduced into the measurements by other sources. Nevertheless the measurement of electric fields in the ionosphere over periods greater than those normally associated with rocket flights is crucial to our understanding of the magnetosphere-ionosphere interactions. A number of other measurements, including x-ray and cosmic ray measurements,could usefully be made from the same balloons or from balloons launched at lower latitudes. For each campaign about three balloons would be required, say one large and two small or intermediate size baloons. At lower latitudes there is need for several balloons per year to study atmospheric constituents. It has been suggested that balloons should also be used as test platforms for sensor development for remote sensing. Indeed, Canada's large geographic extent greatly simplifies the problem of payload recovery and it seems likely that if a continuing balloon program were initiated in Canada, many scientists from other countries would come routinely to Canada to perform their experiments, thereby making the support of the facilities less costly to the Canadian users.

The basic facilities required for a balloon program are those required for launching and telemetry. Such facilities should be available in Canada and be in transportable form so that the various launching sites could be serviced as required. As a minimum,the balloon facilities should be capable of launching simultaneously one large (up to 20 million cu. ft.) balloon and two small balloons from different sites.

There is also a clear need for some organizational structure which will coordinate balloon experiments, arrange

for flights and bring together compatible experiments in single payloads. The more specific recommendation (M1(d)) in the section entitled "Organization" should apply also to balloon experiments. *It is recommended:*

F4 *That three transportable balloon launching facilities (of which one should be capable of handling the very large balloons) be made available for use at a variety of sites in Canada including the campaign stations.*

and

NP4 a) *That the Office of Space Research be responsible for determining the total number and types of balloons needed in the Canadian program and for coordinating the use of the balloons.*

Incoherent Scatter Facility:

It is more than eight years since a small group of Canadian scientists proposed an incoherent scatter radar for study of the upper atmospheric constituents, motions and temperatures. The proposed radar had several novel features that promised to make the facility possibly the most productive in the world. Discussions have continued and in its present form the proposal is for an international facility jointly financed and operated by the U.S.A. and Canada[6]. The main transmitting site and one of the receiving sites would be in the U.S.A. and two other receiving sites would be in Canada. While the facility is generally referred to as making observations at "L=4", in fact it would be capable of providing at least some information about the ionosphere in a region extending all the way from below the U.S.-Canada border to the neighborhood of the auroral zone.

At the present time there is no positive indication that the incoherent scatter facility (sometimes referred to as the Upper Atmosphere Observatory) will be built, although at the time of writing there is some evidence that the continuing interest in the United States may soon be translated into a firm commitment. It is somewhat remark-

able that after all these years the basic concept is still valid and if the radar were built within the next few years it would likely be without parallel as an ionospheric research instrument in the world.

The value of the proposed incoherent scatter facility has been documented elsewhere[7]. All that can be done here is to take note of its possible construction and to recognize the modifications that it would introduce into the space research program. It certainly would become the focal point of much ground-based research on the atmosphere and the ionosphere and would be used cooperatively with scientific satellites. Unfortunately, although rocket flights into the region viewed by the radar would be valuable, it does not seem likely that a launching facility could be placed in an appropriate location due to the population distribution. Flights of balloons and gun-launched vehicles presumably would be feasible. In view of the extensive information provided by the radar it would be simple wisdom to locate sensors in the same area to study the structure, composition and dynamics of all levels of the atmosphere.

Atmospheric Dynamics Network:

In studies of the transfer of energy in the atmosphere, both upwards from the lower atmosphere and downwards from the magnetosphere, one of the key regions in which mechanical motions should be measured is the height range from about 75 to 100 km. A number of techniques have been used for these measurements and there is still some uncertainty about the relative merits of each. Probably the leading contenders are the partial reflection technique which, though expensive, is precise and the meteor winds technique which, though less costly is, in its present form, less precise. There have been strong representations that a significant network (of several stations) should be installed in Canada to monitor atmospheric motions in this important height region. The acceptable size of the network is

necessarily a function of the cost of equipping and operating the stations and it is not clear which technique or combination of techniques should be used. It is probably too early to recommend a specific network. In the meantime an assessment of available techniques should be undertaken with a view to deciding if synoptic measurements of motions in the D region should be included in the aeronomical research program. *It is recommended:*

S1 *That a study be undertaken to dertermine the preferred technique for and extent of a Canadian network of stations to measure atmospheric motions in the 75 - 100 km height range.*

Other observatory functions:

At various times in the past Canada has operated extensive networks of ground-based observatory stations to monitor atmospheric phenomena. The instruments associated with these observatories have included various combinations of ionosondes, riometers, photometers, all-sky cameras, auroral radars and magnetometers. While some synoptic measurements continue to be made with each of these instruments, the present geographic coverage with all but the magnetometers is substantially reduced and some are in the process of being phased out. Strong representations have been made for the reinstitution of significant networks of at least the ionosondes and riometers. These representations are supported by specific recommendations from international scientific associations. It is also true that the modern version of each of these instruments is much more sophisticated than those used for the earlier synoptic measurements. Unfortunately at the present time there is little effort being made in Canada to explore the potential of the new instruments for synoptic measurements that might be of value to the proposed program in aeronomy and space physics. The deployment of an extensive network of ionosondes and riometers would involve substantial expenditures both for equipment and

for its subsequent operation. In the absence of a suitable group of Canadian scientists able and willing to exploit the capabilities of the new instruments for synoptic studies it is inappropriate to make a specific recommendation here. Nevertheless if, in the course of the campaigns proposed earlier, these instruments prove to be so valuable that several Canadian scientists are prepared to use them intensively for ionospheric studies, then consideration might be given to expanding the network to provide more meaningful geographic coverage.

Note on the IMS and IMAP

The reader will have noticed that no mention has been made of the International Magnetospheric Study, a significant future program to which Canada is already committed. Much of the research on the magnetosphere recommended in the preceding section will be a logical outgrowth of the work planned for the IMS. But the IMS will take place in the relatively near term (1976-78) and the present study focusses on the longer term (to 1985). The basic planning for the IMS has been done and, while those plans are heartily endorsed, it is not feasible to recommend major new undertakings that would have a significant impact on Canadian activity under the IMS. Then too, the IMS planning has proceeded on the premise that the Canadian activity will be based largely on existing projects, expanded or intensified by incremental funding. If any part of the proposed restructuring of Canadian space research can be implemented during the IMS it will only increase the effectiveness of the Canadian contribution, since there is no conflict between the short-term goals of the IMS and the long-term goals outlined in this study.

Canadian participation in the International Middle Atmosphere Program is not yet clearly defined, but here again no conflict is seen between that program and the activity in aeronomy proposed in the present study. At the same time, it is important to incorporate the Canadian component of all such major international undertakings into the plans for a Canadian space research program.

The Space Shuttle

This study attempts to look some ten years into the future. Long before that time elapses the space shuttle will become a reality. Although all Canadian space scientists are aware of the timetable for the advent of the shuttle, there is little unanimity of attitude toward its use. We should soon develop a detailed plan for the extent of Canada's participation in the research activities of the shuttle together with a workable mechanism by which Canadian scientists can take part in the experimental program as equal partners with the scientists of other countries. With regard to the mechanism by which a Canadian scientist can propose an experiment and, if accepted, arrange for its funding, this problem is similar to and no more serious than the general problem that confronts any Canadian scientist in attempting to take part in an international space experiment. That problem will be discussed later. Here we will discuss only the possible nature of Canadian participation.

Canada has already undertaken to supply an important mechanism, the remote manipulator, to the shuttle program. The Herzberg Institute of NRC has proposed to supply an important part of the scientific instrumentation, a plasma diagnostics package, to one of the early experimental configurations of the shuttle space-lab. This configuration, known as Atmospheric and Magnetospheric Plasmas in Space (AMPS), will be devoted to magnetospheric and ionospheric studies which fit very well with the proposed central theme of Canada's aeronomy and space physics program. It is understood that NASA would welcome the offer of a further Canadian contribution to the basic instrumentation of the AMPS space-lab in the form of a sophisticated top-side ionospheric sounder. This too would fit well with Canadian interests and Canadian expertise. Serious consideration should be given to using the special competence that exists within the Communications Research Centre to build a new top-side sounder but it may now be too late to incorporate such an equipment in the initial AMPS configuration. In weighing the merits of such an initiative we should be aware that by committing ourselves very heavily to the instrumentation for the AMPS configuration we may be limiting our ability to take up

other attractive options. For example it has been suggested that Canada might "go-it-alone" in providing a complete scientific configuration for shuttle flights. There seems to be no widespread enthusiasm for such a course of action. In fact the space scientists in Canada are remarkably ambivalent in their attitude toward the shuttle. Some regard the shuttle as in many ways being inferior to a completely automatic satellite while others see some merit, but not overwhelming necessity, in having a space experiment attended by an operator/observer. All are aware of the potential value of the shuttle in providing relatively inexpensive launches for small scientific satellites, but realize that this potential may not be exploited until several years after the first shuttle flight in about 1980. If there is a consensus among space scientists it is that Canadian contributions to the scientific configurations of the shuttle/space-lab represent a good investment, but one which may not be recoverable in terms of research opportunities until the shuttle program has progressed to include polar orbits and the space tug.

Among specific suggestions for experiments involving use of the shuttle is remote-sensing both in the conventional meaning of sensing the earth's surface and also including active and passive, optical and radio sensing of the atmosphere and the ionosphere. It has been pointed out that an extremely productive experiment could be based upon an incoherent scatter system mounted in a shuttle module. Any decision about the specific experiments should await a clear definition of Canadian strategy with respect to participation in the total shuttle program. *It is recommended:*

IP1 *That the nature and extent of Canadian involvement in the scientific component of the shuttle program be defined by the Office of Space Research and that consideration be given to further Canadian contributions of hardware to the AMPS shuttle configuration or the later configurations in the series.*

Meteorology

Meteorological satellites

One of the most dramatic early demonstrations of space technology was in the use of satellite imagery for weather forecasting. The display of those images during television weather forecast programs gave to the Canadian citizen a sense of participation in the "space age". The use of APT (Automatic Picture Transmission) satellites has become almost routine. In a typical year the Satellite Data Laboratory of the Atmospheric Environment Service distributes some 30,000 copies of the satellite images to various users. While some of these images are used for research or experimental purposes, the majority are used for operational forecasts and need not concern us here.

The next generation of U.S. satellites will produce very high resolution imagery in both the visible and infra red,and it is expected that those images too will be incorporated rapidly into the operational activities of AES. Indeed the whole field of space-assisted weather forecasting is international in concept and in practice. The U.S.A. tends to provide the leadership in research and technological development and reaps the concomitant rewards in industrial growth. Canada attempts to keep up with the utilization of the new techniques and,as a matter of policy,is committed to following "international", that is, U.S.-Canada joint systems development programs. Certainly for the present,and probably for the future,this approach is completely justified within the context of the operational requirements of the AES. But there is no reason why Canadian research and the resulting Canadian technology could not compete for a place in these "joint" programs. Unfortunately, at the moment the researchers within AES are very much preoccupied with attempting to extend the usefulness of presently available data. They see many ways in which the data might be used effectively and are anxious to explore those possibilities. They argue that since the present research effort is barely enough to "keep up" with a very rapidly developing field,

there is little chance of diverting a significant part of it toward new initiatives. *It is recommended:*

NP5 *That while the studies now being carried out by the Atmospheric Environment Service into the utilization of presently available, remotely-sensed data for computer-based weather forecasts should be continued and expanded if possible, some research effort should be directed toward discovering space-related techniques for acquiring new measurements that are likely to improve the accuracy of weather forecasting.*

Remote-sensing of atmospheric parameters

In fulfilling its mandate within the Department of the Environment, the AES is carrying out a program of research involving measurement of atmospheric constituents, notably ozone, but including also nitrogen, chlorine and fluorine compounds. Canada is in a good position to carry out this research. Canadian science has a long tradition in spectroscopic measurements of the kind that seems to be useful for monitoring these constituents. Much of the work is either ground-based or makes use of balloon-borne instrumentation but an increasing fraction of it will be rocket-and satellite-borne. As mentioned earlier the future of such measurements probably lies in the use of laser scattering, laser absorption and spectrophotometry.

Canada has yet another reason for giving high priority to studies of atmospheric constituents. The motivation for the work is the fear that man is in danger of irreversibly contaminating the atmosphere on a global scale. While many investigations of individual pollutants are being carried out, most of these are being done by the very nations whose industries are suspected of causing the contamination. Some studies are being carried out by the suspected industries. As an independent competent observer, Canada has the capability, and therefore the duty, to carry out investigations which when completed will suffer no loss of credibility in the eyes of the world. Again, a rational long term plan of experimentation, possibly including the use of the shuttle, needs to be formulated which would integrate the AES

space-related research with that of other government, university and industrial groups. *It is recommended:*

NP6 *That the present program of measurements relating to atmospheric constituents within AES should be expanded and coordinated with other research agencies with a view to developing a comprehensive, long-range Canadian service for monitoring of the atmospheric pollutants.*

Use of data platforms

While many of the important atmospheric characteristics, needed for accurate weather forecasting, can be measured adequately by remote-sensing from a satellite, not all are in this category. For example, there is at present no means of remotely sensing atmospheric surface winds over land. It seems likely that within a few years the routine meteorological measurements made at or near the surface of the earth will be acquired through automatic weather stations and that the presence of an operator will be required only at certain special stations such as airports. There is a need then for a means of interrogating a number of remote unmanned stations and thereby collecting meteorological information. A recent study of the requirement for such automatic, remotely-interrogated weather stations, carried out with reference to the proposed UHF satellite, identified a need for some 2000 stations or "data-platforms" for meteorological measurements in Canada. Some of these stations could be connected to existing communication systems, but the majority would be located in places that would not be economically served by conventional land-based communication networks. Already there are experiments in progress using satellites to interrogate data platforms, and much more experimental work is needed. The nature of a possible Canadian experimental program for development of an all-purpose data platform and satellite communication system is discussed separately. Here it is sufficient to point out that the Canadian meteorological requirement is important because of the nature of Canadian geography, but for the same reason there are other, equally important, requirements for data platforms, and once again the research and development for this common

requirement should be coordinated so that the opportunity to develop significant new technology in Canada will not be lost through fragmentation.

Remote-Sensing

The nature of remote-sensing

The activity in remote-sensing differs markedly, and in several ways, from those discussed earlier. It is clearly very applied in that it seeks to return an immediate economic, social or political benefit. It has several components only one of which involves the use of space. At present it makes use only of foreign satellites, and Canada has not participated directly in the building of any of the remote-sensing satellites now in orbit. Finally, many people regard remote-sensing, particularly as exemplified by the Landsat satellites, as being fully operational. If this were so there would be no excuse for discussing it here. But it is not so. Although a few applications such as ice reconnaissance, mapping of forest fire damage and of floods can be regarded as operational, a much larger number of areas of potential applications are still in the experimental stage. If any criticism can be levelled at the extremely enthusiastic and dedicated team at the Canada Centre for Remote-Sensing it is only that they have not quite been able to convey to the potential users the extremely experimental nature of what they are doing.

The potential value of remote-sensing

Remote-sensing has tremendous potential. Much has already been written on this theme but the surface has hardly been scratched. To spend even a few days discussing the potential of remote-sensing with people involved in it is to be convinced that not only should Canada be making its present sincere effort to keep abreast of and make use of new remote-sensing technology but, because of her large unpopulated land mass and her large ocean areas, Canada cannot afford not to invest significantly in remote-sensing research. The investment must be sufficient to keep Canadians near the forefront of remote-sensing technology, a role that is not at all inconsistent with the remarkable amount of pertinent experience that now exists in the Canadian scientific community.

Utilization of present capabilities

But first let us recognize that what is available now, as opposed to what may be available in the future, is four-band Landsat imagery. The value of this imagery to a wide range of users in forestry, geology, geography, hydrology, agriculture, oceanography, navigation and ice-reconnaissance has been demonstrated at least to the satisfaction of some. How then to explain the relatively slow acceptance of remote-sensing for routine use? Perhaps because an operating agency finds it very difficult to change the fundamental nature of its operation while continuing to offer a regular service. Also the interpretation of Landsat imagery is experimental and requires a thorough background in the relevant science. It is rare that this background is combined with complete understanding of the area of application. The Director of the CCRS feels that the universities should soon be providing the potential users with a sufficient background in the relevant physics. It is hard to see how this particular need can be conveyed convincingly to all potential users of remote-sensing, but it is encouraging to note that at least one university[8] is already trying one approach to this training and others are seeking new approaches to it. *It is recommended:*

NP7 *That in support of remote-sensing research the universities be encouraged to initiate the necessary training in science for potential users of remotely sensed data.*

Both of these difficulties could be overcome, at least partially, by encouraging more of the appropriate governmental operating agencies to follow up the present demonstration projects by setting up small independent remote-sensing service groups so that, at least part of the total service of the agency, can be made available both by remote-sensing imagery and by conventional means. If this parallel operation were started within each appropriate governmental agency it would encourage the growth of the necessary interdisciplinary skills, and would provide the beginnings of the new infrastructure needed within the agency to take advantage of remote-sensing. Subsequent decisions to expand or constrict the use of remote-sensing would then depend on its usefulness. This is close

to the procedure being adopted in the U.S.A. where many federal agencies can obtain additional funds to set up this parallel kind of operation.

In the area of resources most of the provinces have already set up groups to manage the provincial responsibilities with respect to remote-sensing. This is a fruitful area for federal-provincial collaboration, and active participation by the provinces may speed the process of user acceptance.

The future

For the future, there are a host of new and exciting techniques emerging. In optical sensors the emphasis will probably be on reflection spectroscopy and on lidar probing of the atmosphere and water. One of Canada's most important potential contributions to remote-sensing is in the area of electromagnetic remote-sensing and specifically in synthetic aperture radar processors. With both radiometric and active electromagnetic sensors a satellite could provide all-weather surveillance of coastal waters, it could locate ships, continuously monitor ice and sea state, and thereby make an invaluable contribution to the management of all coastal and continental shelf waters, but particularly of those in the Arctic. Plans are already well advanced for Canada's active participation in the U.S.A. Seasat program. This should be followed by a well planned series of steps over the next five years culminating in a satellite with one or more Canadian sensors aboard. Whether this should be a satellite completely dedicated to remote-sensing and shared with the U.S.A or E.S.A. or Japan, or whether it should be a Canadian satellite with a mixed payload, partly remote-sensing, partly space science, is hard to determine at the present time. What is important is that there be a program with assured continuity that will keep Canadian science, Canadian industry and Canadian users near the forefront of remote-sensing technology.

Some Canadian agencies, faced with the explosion in remote-sensing technology, have been tempted to adopt a rather passive

attitude. They are inclined to keep a "watching brief" on the field, trying to keep informed about developments but not initiating any new developments. This may be expedient but carries with it the danger of eventually being unable to digress from the program goals even when Canadian interests would be better served by digression.

As the technology of remote-sensing improves it seems likely that there will be increasing friction between the "sensing" nations and the "sensed" nations. The present attitude toward this problem seems to be to "internationalize" remote-sensing satellites, that is to use only general purpose satellites, and to give all nations access to the sensor data by direct readout. But it cannot be too long before individual nations, including particularly Canada, develop requirements for sensors that are specialized to their national needs. If these sensors are placed aboard satellites it becomes important that the satellites be seen to be capable of sensing only the territory of the owner nation. This could be done by placing a satellite in a geosynchronous orbit. While the 24 hour orbit could be acceptable a better solution would seem to be a highly elliptical,12-hour orbit inclined so that the satellite has a dwell time of several hours over the centre of the Canadian territory. It is not likely that the 12-hour orbit would be practical for remote electromagnetic sensing but it would be very suitable for optical remote-sensing. Again before serious consideration is given to a 12 hour orbit for remote-sensing there is need to know more about the space environment associated with a highly-inclined elliptical orbit. In any case there is need for a plan. *It is recommended:*

NP8 *That a specific plan, including timetable, be developed for remote-sensing research and sensor development to ensure that Canada shall have within, say, ten years, an adequate capability in satellite remote-sensing of our land-based resources and in all-weather ice and ship surveillance of the neighbouring oceans.*

Space Astronomy

The 1974 recommendations

In its widely distributed and widely discussed 1974 report[9] the Associate Committee on Astronomy drew attention to the growing importance of astronomy to the world of science, and to the growing importance of space science to astronomy — "Canadian astronomers recognize that observations from space platforms will inevitably dominate astronomical research trends in the near future". The recommendations of that report emphasize two requirements. The first of these is the need to integrate Canadian space astronomy into the larger context of Canadian space research. The second is the need for orderly planning of the participation by Canadian astronomers in international programs, and the provision of the necessary assistance to ensure that a Canadian astronomer can compete for a place in an international program on an equitable basis.

The reaction of the astronomical community

In order to assist with the preparation of this report the Associate Committee on Astronomy undertook to poll members of the Canadian astronomical community regarding their current attitudes toward space activities. This was done by a committee chaired by Dr. R.W. Nicholls of York University. Again there was overwhelming recognition of the importance of space activity to the future of astronomy, but a few comments may serve to place the response of the astronomers in perspective.

The total astronomical community in Canada numbers some 150. In this community there is a continuous spectrum of attitudes extending from those who are interested primarily in ground-based observations to those who are interested primarily in space-based observations. Typical of the former is the astronomer who has as his principal interest the study of some astronomical object or phenomenon which can be studied adequately by observations made with ground-based instruments. Even if space-borne instruments could provide improved observations he is inclined to wait until the space-based observations become available as a result of the

rapidly developing U.S. and ESA comprehensive space programs. He is secure in the knowledge that if he is sufficiently recognized as an authority in his own area of study, he will have no difficulty in gaining access to the space data when it becomes available. For many Canadian astronomers this expectation is clearly justified and they must have been well represented among those who did not respond to the questionnaire as well as among those who did. In all some 60 people responded.

At the other end of the spectrum is a small group of astronomers who are so enthusiastic about the potential of space astronomy that they are willing,not only to re-orient their individual research interests toward space-related studies,but they are anxious to get involved in the design and construction of space hardware. This group includes both the limited number of people who have had experience with rocket-borne observations in the ultraviolet and x-ray region of the spectrum,and the somewhat larger group of infra-red astronomers who have had less experience with space-borne observations.

The limited use of rockets in Canada for astronomical research is understandable. Collimation of high energy photons is difficult and requires complicated payloads. Observations in the infra-red usually require cryogenic facilities. In addition most astronomical observations require accurate pointing capability, and this has only very recently become available in the Canadian rocket program. Then too, some of the early experimenters have become disenchanted by what they regard as the inordinately long time required to carry out an experiment in space with the current level of funding. Some point out with some bitterness that space astronomy is a rapidly developing field on the international scene, and if it takes three or more years of conventional university grants in order to develop a single observational payload it is likely that the experiment will be overtaken by others before it is flown. On the other hand, effective use has been made of balloons in Canada for certain astronomical studies, notably infra-red investigations of solar phenomena. Balloons are ideally

suited to these studies because they provide large weight-lifting capability (for the cryogenic apparatus) and long observing time. A large fraction of the balloon program in the U.S.A. is devoted to astronomical observation and Canadian astronomers are hampered by the lack of suitable platforms. The requirements in astronomy should also be incorporated into the previously proposed plan for balloon activities in Canada.

In contrast to the groups discussed above there is another significant group made up of Canadian astronomers who are well integrated into the U.S. space astronomy program either as a result of earlier direct participation while resident in the U.S.A. or as a result of an invitation to assist with the project definition and/or the analysis of data. Understandably, this group sees little benefit in a distinctly Canadian program of space astronomy unless it expands in some way that of the U.S.A. Indeed, in view of the very great emphasis on astronomy in the NASA program it seems unlikely that Canada could develop an area of independent competitive strength without a concentration of funds out of all proportion to its present space expenditures.

The options

There is some feeling that, since space astronomy is clearly becoming more and more important to astronomy and to science, the increased participation of Canadian astronomers in space activities should be "forced", presumably by selective funding. Not only is this approach distasteful, it is inconsistent with recent developments. The whole field of astronomy has grown rapidly in Canada over the last few years, spurred by substantial investments in new ground-based telescopes. The astronomical community is gearing itself to make adequate use of these new facilities, and the graduate schools are concentrating on turning out appropriately trained professional astronomers and astrophysicists. A reasonable return on the recent expenditures will be gained only if this process is allowed to continue.

How then may we satisfy the legitimate aspirations of the small but growing number of space astronomers who want to participate

in the exciting frontier research of their field now? It is interesting to examine the response of other countries to this situation. The European countries, notably France, have recognized the inability of individual groups to "go-it-alone" in space astronomy. The approach adopted by ESA is to evaluate the level of expenditure appropriate to the projected participation of European scientists, and to "buy" an appropriate fraction of the international program, both by instrumenting their own satellite and rocket experiments and by providing basic instruments to the shuttle configuration. Such joint programs as the International Ultraviolet Explorer and the Large Space Telescope are examples. The general rule in these bilateral and multilateral agreements seems to be that the observing time for European scientists will be in direct proportion to the European contribution as a fraction of the total cost of the project. This approach not only ensures adequate access to the scientific activities, but also secures concomitant industrial activity in the participating nations. Undoubtedly, from the point of view of the participating nation, the opportunity to bring its industrial sector to the forefront of technology is regarded as no less important than the participation of its scientists at the forefront of science.

Such realistic and mutually beneficial bargaining for a place in international programs of space astronomy is not now possible in Canada. One objective of any coordinating agency for space research in Canada should be to ensure an equitable participation of Canadian astronomers and of Canadian industry in large scale international projects. *It is recommended:*

IP2 *That the Office of Space Research seek bilateral agreements which would provide interested Canadian space astronomers with an appropriate amount of observing time on space telescopes including both shuttle-mounted telescopes and shuttle-launched space telescopes.*

and

NP3 b) and NP4 b) * *That in order to permit Canadian space astronomers to make realistic proposals for space experiments in international programs the evaluation and funding of the necessary preliminary rocket and balloon experiments be initiated.*

* In the interests of brevity and coherence the two similar recommendations NP3 (rocket) and NP4 (balloons) are here combined.

The Life Sciences

The space research programs of both the U.S.A. and the U.S.S.R. have each had a significant continuing component in the life sciences. In spite of many efforts over the last fifteen years to encourage the participation of life scientists in Canadian space activity, the total involvement by life scientists has been meagre. In searching for the explanation of this fact one can point to the failure to provide suitable platforms for space-oriented experiments in the life sciences, but this leads only to a circular argument; why was there no demand for suitable platforms? Certainly not because there is no mature community of life scientists in Canada. In the course of the present study an attempt was made once again to explore the degree of interest in space-related research among the life scientists in Canada. The only positive responses were received from medical scientists, but it is difficult to see how to translate these responses into concrete program proposals.

Medical science

Two extensive submissions were received from medical scientists, one from a scientist with substantial experience in the NASA program, and the other from a scientist without such experience who is anxious to participate in future NASA experiments, including those involving the space shuttle (see Appendix II). Both submissions documented the extensive benefits to medical science that have been obtained from the NASA programs including particularly the Apollo and Skylab programs. The experiments have added much new knowledge about the ability of the human to survive, adapt and work in space, but more importantly the experiments have added new knowledge about the functioning of the various human body systems. In addition, fundamental and useful new insights were provided into the utilization and management of food and of body wastes.

There are many important experiments still to be done in space using human or animal subjects. The experiments relate to: Biochemical responses of the human body, cytogenetic effects, fluid

balance, cardiac and pulmonary functions, blood volume changes, toxicology and neurobiological effects. It seems likely that these experiments will be done, and that the level of activity will increase greatly when the shuttle is available. The order in which the experiments are done, and the relative emphasis placed on each, will be determined by the scientists involved. At most, there can be only a handful of medical scientists in Canada anxious to take part in the preparation and interpretation of space experiments.

Given the small number of Canadian medical scientists now interested in space experiments it seems important to stimulate further interest, but good research will be done only if the interest thus stimulated will sustain continuing and active participation by a significant number of people. In the meantime assistance should be given to those scientists who are now participating or are anxious to participate in international programs. *It is recommended:*

IP3 *That in collaboration with the Medical Research Council assistance by means of bilateral agreements be given to medical scientists to permit them to participate in space experiments including the shuttle-borne experiments.*

Biological science

Through the willing cooperation of Dr. D.B. Walden, President of the Biological Council of Canada, the views of key people in biological research were solicited. The request was widely distributed. Unfortunately no responses were received within the two month period provided. This lack of response was particularly disappointing since it is known that a small but significant number of agriculturists, plant biologists and animal biologists are exploring the application of remote imagery to research problems. Possibly the failure to respond on the part of these people is due to the fact that they regard the space component of their research as an important, but not paramount, facet of their programs.

Typical of the present activity in this area is the comprehensive program of research on seals being carried out at the University of Guelph by a team led by Prof. Keith Ronald. This is a multidisciplinary project pursued by a multidisciplinary team. The techniques used include direct observation of the seals by a ground observer and from helicopters, and investigation of the seal movements by observation from aircraft. Landsat imagery is used to study characteristics of the habitat. The group has already made some valuable contributions to the technique of image processing in order to enhance the features of importance to the study.

At the present time it would seem that the most important contribution that space science can make to biological studies is in the area of remote-sensing, and this contribution may well revolutionize the research methods used in some areas of plant and animal science. But again, though the potential exists, active research is needed to exploit the application of remote-sensing. As in other areas of remote-sensing, there is need for positive action to bridge the interdisciplinary gap between those interested in the sensors and those interested in the use of these techniques for research in the biological sciences. In due course, utilization of remotely-sensed data by the biologists of other countries will persuade Canadian biologists to take up this new research tool. In the meantime research opportunities are being lost. *It is recommended:*

S2 *That the national biological associations in Canada be invited to study the new research opportunities provided by the present and future generations of remote-sensing satellites with a view to stimulating active participation of biologists in the refinement of remote-sensing techniques for biological research.*

Cosmic Rays

Historically it has been usual in Canada to consider that the general field of study of cosmic rays is part of space physics. Actually, judged by present activity, only part of cosmic ray research could be specifically designated as space research. Some of it would be properly classified as solar physics, some as high energy physics. Nevertheless during the preparation of this report a number of cosmic ray researchers were interviewed and some, notably those at the University of Calgary, were anxious that their views should be included. The serious difficulty in which they find themselves has been documented by D.Venkatesan in a brief entitled "Report on Cosmic Rays".

The 1950's and 1960's saw a period of peak activity in cosmic rays, and the 70's have seen a contraction in the number of groups so that now, although there is some work being continued at the NRC (Herzberg Institute), the principal concentration of researchers is at the University of Calgary. During the 60's there was a substantial network of superneutron monitor stations in Canada, but several of these have been closed down. Two continue to be operated by the Calgary group, and the long series of data (extending back to 1964 and 1963) produced by the monitors have been put to very good use both by the Calgary group and by the rest of the scientific community. The uncertainty about whether or not cosmic rays should be classified as space research leaves the Calgary group feeling somewhat isolated and a little suspicious that their work is not being fairly evaluated. They point out that the continuation of the long series of superneutron monitor data will not be possible for long as the costs of operation go up and the level of funding goes down. It would be unfair and unproductive to attempt in this report to evaluate the argument for continuing the operation of the monitors. Clearly, if it has not already been done, some such evaluation should be undertaken by a funding agency. *It is recommended:*

S3 *That an appropriate NRC committee institute an early review of the present support of cosmic ray research in Canada, particularly with reference to the superneutron monitor network. The objective of the review should be a decision either to support the monitor network over several years or to phase out the network.*

On the other hand, several important experiments can be carried out using balloons and rockets. With respect to balloons, the cosmic ray researchers have a further complaint and it is surely valid. In the absence of any organized and centrally-funded balloon program in Canada each experimenter must search out agencies who happen to plan balloon flights in Canada and then beg passage for his equipment aboard. At least this difficulty could be overcome by the institution of a Canadian balloon program based on domestic launch facilities, as already has been proposed. The requirement for balloon launches for cosmic ray experiments, while not large, is important because there seems to be no other feasible way of carrying out those particular experiments. This is another reason why we must have a continuing balloon program in Canada. *It is recommended:*

NP4 c) *That the needs of the cosmic ray researchers for balloon flights be considered in formulating the plan for an integrated program of balloon flights in Canada.*

Space Processing

One aspect of space science that has received little attention in Canada is space processing. The term refers to the application of space flight to materials science and technology. The NASA program of Apollo and Skylab experiments has included experiments designed to increase knowledge in the areas of: electronic materials; biological preparation; metallurgical processes; glass and ceramics; physical processes in fluids; and chemical processes. During the hiatus in manned space flights between Skylab and the space shuttle, NASA is sponsoring a vigorous program of rocket firings, based on Black Brant VC vehicles, in order to ensure that space processing research continues and is in a position to take full advantage of the shuttle when it becomes available. Already the Skylab experimental results are regarded as "tending to confirm the belief that space has unique advantages for some kinds of materials research". Apparently about a third of the experiments produced unexpected results. Also, recently there seems to be some interest in carrying out research on pharmaceutical processing in space. Clearly, there are many processes which might be better understood as a result of experimentation under "weightless" conditions.

The present study did not reveal more than an academic interest in the subject of space processing among Canadian scientists although it is understood that, for example, several Canadian metallurgists have been involved in the NASA program to the extent of participating in the pre-flight and post-flight discussions of the experiments. Once again, direct involvement in the U.S. program may be the only logical method by which a Canadian scientist can take part in this new area of research. However, as in other areas, the research activity is progressing at such a rate that it will be increasingly difficult in the future for a scientist with no space-related experience to gain entry to the program. The major opportunity will come with the shuttle, but if Canada is to play any part in the field of space processing it should now be

carrying out the necessary preliminary experiments in rockets. The decision to provide rocket flights to be devoted to space processing must necessarily await the evaluation of the degree of interest among Canadian scientists. Although the knowledge gained in this field will undoubtedly increase our fundamental understanding in many areas of physics, biology and chemistry, and is also likely to be of direct benefit to industry, it may be another example of an area which we should not enter at this time in order to concentrate efforts elsewhere. *It is recommended:*

S4 *That the degree of interest in space processing within Canada be assessed to see if a series of rocket flights devoted to space processing is justified. Such rocket experiments would be preliminary to submission of Canadian experiments to the shuttle program.*

Data Platforms

It has been pointed out (under Meteorology) that there appears to be a need in Canada in the foreseeable future for a large number of data platforms or unmanned automatic stations capable of transmitting short data messages to a satellite relay station for subsequent collection at a central ground station. The need is by no means exclusive to meteorology. There are also many other functions that could be carried out with the aid of data platforms including the monitoring of pollution, of water resources, of light-house operation, of fishing fleets and of many other of the physical conditions of the oceans and of remote land areas. There is also a potential application of the techniques involved to Air-Sea Rescue operations. In carrying out his study for the proposed UHF satellite, Mr. O. Roscoe, Communications Canada, identified a potential requirement totalling some 7000 platforms. Nor is the requirement peculiar to Canada. While many of the uses cited would be specific to Canadian needs as reflected in the requirements of Canadian government departments, other countries have similar needs. Indeed, it has been suggested that within twenty years or less,the whole surface of the globe will be covered with data platforms to a density similar to that suggested by the forecast of the Canadian requirement.

Clearly, Canada should be doing something about data platforms and to a limited extent something is being done. Bristol Aerospace Ltd. is developing an experimental data platform to be deployed in the Beaufort Sea. This project is interesting and imaginative. The platform will derive its power from a wind-powered generator and every effort is being made to ensure that the sensors, data-handling equipment, transmitter and indeed the whole platform will operate reliably for long periods of time in a very hostile environment.

The contributions that the data platforms can make to more fundamental research should not be overlooked. The need for some twelve remote unmanned stations to operate in conjunction with the campaign stations for aeronomy and space physics already has been outlined. Fundamental research in many other disciplines also

would be expected to benefit from such widespread collection of data in nearly real time.

The difficulty with the present approach to the acquisition and use of data platforms is that, in common with most other space applications, each agency is either starting an experimental program, or considering the initiation of a small-scale program. Each of these tentative limited proposals is too small to justify a full-scale development and assessment program, and as a result, each leads inevitably to the conclusion that it is feasible only to adopt, or modify and adopt, existing hardware. But if the total requirement is even a fraction of that outlined above there is ample scope for a full-scale industrial development program at least for the data-platform component of the system. There may be a further argument that Canada should either build or be a partner in the building of the satellite component. Certainly some of the most important and challenging aspects of a large-scale data platform system are in the data handling. The collection of so large a body of data, its division into appropriate "suites", and its subsequent distribution to appropriate users with delays of at most a few hours, represent an undertaking that will demand the development of new techniques. G. Rostoker and J.V. Olson have argued the case for a Canadian research and development program that would involve all sectors and be aimed toward the provision of a highly efficient, highly reliable data platform network in Canada. Their brief is entitled "The Priority Project for Canadian Space Research." While they based their analysis on a network of one hundred stations, they recognized that the actual need might be in thousands, and the larger requirement merely reinforces their arguments. As is pointed out in their paper the magnitude of even their minimal program is of a size to dwarf the individual Canadian space projects of the past, and would force another step forward in many branches of "high technology" in industry.

In the meantime the initiative has been seized by others. The French Space Agency has just announced the ARGOS system for data retrieval from remote automatic stations. The system comprises

the data platforms (available from the CNES, or built to specifications provided by CNES), the receiving and data storage facilities aboard the TIROS-N satellites operated by N.O.A.A., and the central data processing centre at Toulouse. It will provide worldwide, 24 hour-a-day, coverage with an average of four contacts per data platform per day. The system will handle up to 16,000 data platforms and will be operational from 1978 to 1986. It provides the additional capability of locating individual platforms with an accuracy of 3-5 km, but can handle only 4000 platforms in this mode.

The ARGOS system falls short of that envisaged by Rostoker and Olson in that it cannot interrogate individual platforms. This capability is of considerable value, but the case made by Rostoker and Olson would need to be evaluated in detail in the light of the ARGOS capability when the ARGOS prices are known. Only then could a decision be made as to whether Canada should opt for the ARGOS system to fulfill its requirements or undertake the development of a more sophisticated system that would better meet Canadian requirements and presumably those of other countries. Even if the decision be to adopt a foreign system, an aggressive program of sensor research and total platform development should be started in Canada. The present capability of our industrial sector would suggest that a vigorous program could well lead to a state-of-the-art system of data platforms which could command a substantial export market. *It is recommended:*

S5 *That the need for scientific data acquisition from remote platforms be evaluated in relation to the total Canadian requirement for data platforms, with a view to either adopting an existing system, such as the ARGOS system, or starting a research and development program aimed at producing a more suitable data platform system for Canada. If the decision is to adopt an existing system, consideration should still be given to undertaking a research and development program involving all sectors and directed toward all aspects of automatic stations including sensors, data storage and format devices, and environmental protection.*

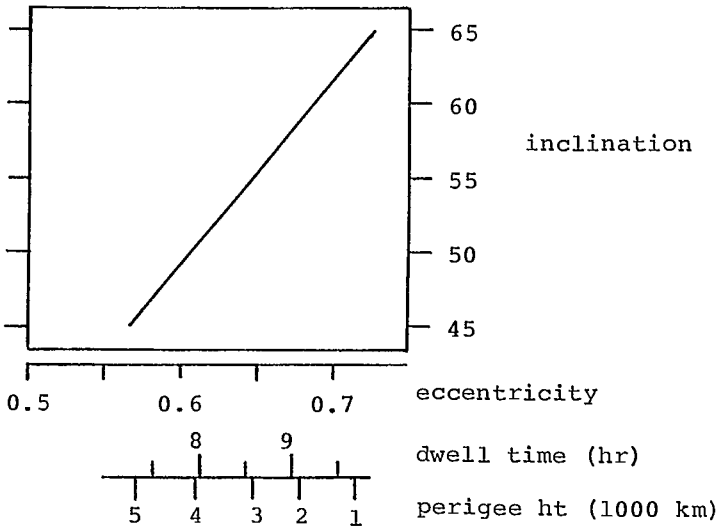
Special Orbits

Seven Canadian satellites have been placed in orbit. Four of these in the Alouette/ISIS series were research satellites launched into near-polar circular or near-circular orbits. The remaining three were Anik communications satellites in geostationary orbits. These will soon be joined by the CTS communications technology satellite, also in a geostationary orbit. The purpose of this section is to draw attention to the utility of highly elliptical orbits both for research and for applications satellites. The value of such orbits for research on the space environment has already been pointed out (under Aeronomy and Space Physics). Aside from the new fundamental knowledge of space that a highly elliptical orbit could provide, there is a more practical reason for acquiring detailed knowledge of the environment encountered by a satellite in such an orbit. For a country with much territory at high latitude, one particular elliptical orbit, that with a 12 hour period, is particularly useful for communications and for remote-sensing using optical imaging. The USSR, whose territory covers roughly the same latitudinal range as that of Canada, has for several years used such orbits for its communication satellites. Further, the over-population of the equatorial belt with geostationary communication satellites is becoming ever more imminent as more and more satellites go into that orbit. Eventually it seems likely that new communication satellites will be forced into inclined orbits, and of these the 12-hour highly elliptical inclined orbit seems the most useful. It is important therefore to do the basic research related to the environment of the orbit before it is needed for a space application.

The usual objections to orbits other than geostationary are that they do not provide 24-hour availability, and they impose difficult tracking requirements on the ground station. It does not seem to be generally recognized that certain of the 12-hour orbits have a remarkably long dwell time over a particular region of the earth, and as a result, are easily tracked by a receiving antenna that moves in only one plane. For example, it is quite possible to

choose an elliptical 12-hour orbit with perigee within a few thousand kilometres of the earth and apogee beyond the usual geostationary radius to give a dwell time within one degree of the meridian of more than eight hours. Only three such satellites could provide complete 24-hour coverage for all of the Canadian territory including the high arctic.

As background for this study Dr. F.H. Palmer of the Communications Research Centre investigated the characteristics of this particular type of 12-hour orbit and provided the data for the graph of the accompanying figure which gives the dwell time (defined as the time that the subsatellite point spends within one degree of the meridian of the observing station), the eccentricity of the orbit necessary to achieve that orbit, the height of perigee above the surface of the earth and the inclination of the orbit. For example, with an inclination of 63° (about that of the Russian Molniya communication satellite), perigee distance of about 1200 km and eccentricity of about 0.71, the dwell time is more than 9 hours 30 min out of a total orbit period of 12 hours.



Orbital relationships for 12-hr orbits that remain within ±1° of meridian for the dwell time indicated,

There are other families of potentially useful geosynchronous orbits. The DASP paper draws attention to the highly elliptical 6 hour orbits. There is also the possibility of using elliptical 24 hour orbits. Dr. Palmer has pointed out that some of these latter orbits also provide the possibility of one-axis tracking (although the tracking is in "hour-angle" rather than in declination as required for the 12-hour orbits). For example, a 24-hour elliptical orbit with an eccentricity of 0.825 and inclination of 30° would remain visible to a single-axis tracking antenna for substantially longer than 12 hours in each orbit.

It seems that inclined, highly elliptical, 12-hour or 24-hour orbits may well be usefully exploited by Canada in the future. For that reason it would be wise to seek an early opportunity to gain experience with such orbits. *It is recommended:*

F1 b) *That early consideration be given to placing an experimental satellite in a 12-hour elliptical orbit at an inclination of about 60°, or a 24-hour elliptical orbit of lower inclination, to investigate both the space environment of the orbit and its utility for remote-sensing and other applications.*

Gun-Launched Vehicles

The relative merits of using a gun as opposed to a rocket to place an experimental payload in at least the near regions of space have long been debated, and probably nowhere more than in Canada. While most previous studies have agreed that the gun-launching technique displayed some promise of usefulness, they all agreed that there was a substantial mismatch between the then current objective of the gun-launched vehicle program (as typified by the HARP program, see an earlier study[10]) and the then current Canadian requirements. While the present study had no opportunity to examine the 1975 version of gun-launching facilities in detail it is obvious that the situation has changed significantly since the previous evaluations.

Gun-launching techniques are now concentrated in the area where the techniques provide the greatest advantage, that is in launching payloads to heights of about 100 km. In this height range gun-launching provides some significant advantages, primarily economy and accuracy. A seven-or eight-inch gun-launching should cost about $350 for the vehicle and $150 for the powder to launch it to a height of about 100 km. The gun is mobile, and complete with its tracking radar should cost about $150,000. These costs are very attractive. Additionally it is an inherent characteristic of high-velocity launches that the impact area can be accurately predicted, usually to within less than two kilometres for gun-launched payloads. However there are disadvantages including very limited payload mass and volume. The most important disadvantage is very high acceleration forces (typically 40,000 g) at launch. Nevertheless the Space Research Corporation has developed and successfully flown a variety of electronic packages including telemetry packages and meteorological sensor-transducer packages.

One of the most frequently used configurations of the gun-launched vehicle is for passive payloads. These vehicles are regularly used to deploy chemical clouds (such as cesium or barium) in the upper atmosphere for the purpose of initiating an electron

cloud or for examining atmospheric motions. The possibility should be seriously explored that gun-launched vehicles could fit into the Canadian program of upper atmosphere research, and in so doing, provide significant economies. The accuracy and mobility of the launching system (gun) are extremely attractive for expeditions to remote areas. It may be that the inherent accuracy of the gun-launching system would permit its use in regions not accessible to rockets, as for example in the region to be overlooked by the incoherent scatter system.

In any case it behooves Canadian scientists (and Canadian science managers) to keep a close watch on the development of the gun-launching techniques because for a limited range of application it is likely that it will be the technique of choice in the future. *It is recommended:*

S6 *That a new evaluation be made of gun-launching techniques for those research applications in which a payload is to be lifted to a height of about 100 km and where economy is important (as in synoptic studies).*

Organization

Comments on existing structure

The earlier sections have dealt in some detail with the changes necessary to improve the effectiveness of space research, and by implication have indicated what is wrong with the present organization of the research. Basically, the organization of space research is too fragmented. Space research represents a small part of the mandate of each of the governmental departments that have an interest in space activities. For none of the agencies represented on the Interdepartmental Committee on Space is space research of primary importance. Viewed from the position of each agency this may be entirely appropriate. But viewed from any position that sets a high value on the general good in Canada the present situation is not appropriate, because space research is too important to the future of Canada to permit it to be pursued spasmodically or ineffectively.

The fragmentation of space research extends also to the university and industrial sectors. Since the funding is piecemeal the work is piecemeal and the result is much less valuable than it could be or would be if only there were some means of coordinating the activity in pursuit of a small number of well-chosen goals. This fragmentation causes the university research to be less productive than it should be, but the effect on the industrial sector is more serious. The fragmentation in the governmental and university sectors means that industry is continually being approached with proposals for developments, each of which is too limited to be commercially viable. As was pointed out in the section under Data Platforms, the usual result is that each user turns to foreign industry to supply his needs. There are some exceptions. Recently a few very small Canadian companies have been able to turn small single-unit development contracts into significant export sales. This happy outcome seems to be due to the twin circumstances of the limited size of the companies and remarkable perception (or faith) on the part of the contracting agencies. Had the individual company been much larger it would not have been

economically feasible to undertake a single-unit development project. Had the contracting agency looked only at the competitive cost of the single unit being developed it might well have been tempted to do the development "in house", or to modify the specifications to fit an existing foreign-made item. In any case, there are three or four small industrial firms in Canada which have made a remarkable impact on the international, space-related market. The larger firms need larger projects to utilize their much larger engineering teams in order to remain competitive in the international market. And they need the continuity of activity that can only come from a long-term plan. There are those who argue, as did an earlier study[10], that Canada needs an all-encompassing Space Agency. Certainly most countries with significant space interests have chosen that structure. Indeed, the concept of a single agency to supervise all space activities seems now, finally, to have been translated into a workable structure at the multinational level in ESA (the European Space Agency). Nevertheless the position adopted in what follows is that to recommend the establishment of a Canadian Space Agency is beyond the terms of reference of this paper. Any solution to the present difficulty must be worked out as much as possible within the framework of present structures.

A suggested structure

In order to concentrate the responsibility for ensuring the productivity of space research it seems to be essential to designate one agency of government as the lead agency for space research. Subject only to its willingness to accept the responsibility, the NRC is the logical agency to be so designated. In accepting this responsibility the lead agency should ensure the existence of adequate internal and external organizational structures to provide supervision of the total space research effort in Canada.

Office of Space Research:

The lead agency should set up an Office of Space Research as the central unit to carry out the formulation of a long-

term plan and its effective prosecution. This office would need to cooperate closely with other government agencies, with universities and with industries, if the objectives of the research plan are to be achieved. Mechanisms for liaison with universities and with industry are outlined below. A rational mechanism for liaison with the other government departments already exists in the ICS But because the ICS responsibilities extend beyond research and because there needs to be a strong spokesman for research interests on the ICS the director of the Office of Space Research should be the lead agency's representative on the ICS In addition there should be a formal advisory link between the research groups in each department and the Office of Space Research.

While the Office of Space Research (OSR) is envisaged as primarily a supervisory and administrative organization there are some operational functions that clearly should be placed under its direct administrative control. Principally these functions have to do with the establishment and operation of facilities which are used by several groups of researchers, and which cannot conveniently and economically be managed in any other way. There should be an operating branch of the OSR responsible for all of these functions. At the present time the Space Research Facilities Branch of NRC carries out these functions with respect to rocket flights and in some other limited areas, but the present suggestion would include also, ground stations of the kind described earlier as campaign stations, balloon flights and research satellite operations.

Corporation for University Space Science:

The effects of fragmentation of research in the universities described earlier can only be reversed by cooperative planning and cooperative execution of research with well-chosen objectives. The obvious technique for obtaining this

degree of cooperation among university researchers is to set up a Corporation of University Space Science (CUSS). It is suggested that this should be an incorporated body in which each interested university would have a share and a representative on the Board of Directors. The responsibility of the CUSS would be as follows:

(i) To draw up an initial plan for a program of university space research extending over five to ten years (to be revised annually) and present it to the OSR for evaluation.

(ii) To manage the agreed-upon program under the supervision of the OSR and in cooperation with the OSR and other governmental agencies.

(iii) To negotiate with the OSR regarding the funding of the program and, as part of the management function, to disburse the funds to the universities for specific projects with agreed-upon objectives and timetables.

There are many precedents for such an organization among the universities of the United States. Indeed one Canadian university (U. of Toronto) is already a member of the Universities Space Research Association which has a membership of some 50 North American universities. The DASP paper makes a case for the setting up of a consortium of universities to supervise the aeronomy and space physics program. Since that program is bound to overlap with others such as meteorology and remote-sensing, the present suggestion is for a single entity to oversee all of university based space research (but noting and accepting the recommendation of the DASP paper that there should be alternative funding for the individual researcher who wishes to work alone). There have been other suggestions that instead of one Corporation there should be several university centres each concentrating on one aspect of space research and involving researchers from other universities. This concept is not incompatible with the Corporation but may be unnecessary. In any case the universities must make the final decision as to the nature of the cooperative structure. The need is obvious. There

must be a collectivity of researchers with which OSR can deal directly. If the OSR were to deal separately with each individual university researcher the university sector would be excluded from the planning process, where its voice is needed, and the centrifugal tendencies of the present system would be perpetuated.

Industrial Associations:

Just as there is need for the university researchers to take part in the planning of the total research program, so there is need for an industrial voice in planning the participation of industry in the program. A good deal of cooperative accommodation is necessary between all three sectors if maximum benefit is to be gained from a space research program. From the industrial point of view this means not only fitting together the space research requirements in an orderly manner but fitting these with the other space activities, and even with major technological non-space programs. Existing or future industrial associations may be helpful, and in some cases industries may wish to form consortia for the management of specific projects. There are obvious difficulties associated with commercial advantage and legal constraints, but the OSR will need to seek ways of obtaining appropriate industrial participation in the planning of industrial activity.

In order to achieve all of the objectives outlined above a single major recommendation is submitted. *It is recommended:*

M1 *That an agency of Government, such as the National Research Council, be designated the lead agency for space research and that it set up an Office of Space Research. The director of the Office should be a member of the Interdepartmental Committee on Space. The Office should have the following specific responsibilities:*

a) Initially to draw up, in consultation with the various sectors, a five-year program with projections to ten years for space research activity in Canada, and to revise the five-year plan and the ten-year

projections annually. In drawing up the plan the Office of Space Research should examine, evaluate and set priorities on the detailed recommendations of this report with a view to incorporating, on an appropriate time scale, those that retain their significance in the light of changing national and international conditions.

b) To invite the universities with significant involvement in space research to form an incorporated association to plan, propose and manage space research in the university sector.

c) To receive and assess proposals from the association of universities, to arrange funding and to supervise the carrying out of the approved research program by the association of universities.

d) To arrange for the availability of all those facilities for space research which are used by a number of research groups. This should include specifically, rockets, balloons, scientific satellites, campaign stations and data platforms used for research purposes. In carrying out this responsibility the Office of Space Research should draw upon existing capabilities in government. laboratories, in industry and in universities, and make provision for those facilities where there is no existing capability.

e) To seek the cooperation of the appropriate government agencies in carrying out the research plan, both through the Interdepartmental Committee on Space, and through direct bilateral arrangements with government laboratories.

f) To incorporate into the overall program reasonable mechanisms by which Canadian groups can participate in international undertakings in space research. This should include involvement in the definition of international missions, funding of conceptual design and feasibility studies, and commitment to fund those proposals that finally are accepted.

g) To arrange for the efficient use of all available manpower and funds in achieving the program objectives, and to take the initiative in seeking new resources where these are required to meet the needs of the program. (See also detailed recommendations 01, 02 and 03.)

Associate Committee on Space Research:

This committee has played an important but highly variable role in the development of Canadian space research. In its

early years it was instrumental in bringing about many of the cooperative projects that contributed to the success of Canadian research. Later it suffered a loss of effectiveness (and credibility) that closely paralleled the loss of effectiveness of the total research program in Canada. There are some who attribute this wane in influence to the assumption by the committee of a second role, that of acting as a scientific advisory committee to the Interdepartmental Committee on Space. Recently the Associate Committee has been reorganized and revitalized and has shown a willingness to take new initiatives (including, of course, the commissioning of the present study).

It may appear that implementation of the organizational recommendations of the study will diminish the role of the Associate Committee. In some respects this may be true, but in other respects its role will be enhanced. Although the OSR will have a number of direct lines of communication to all sectors of the space research community it, like most supervisory agencies, will be preoccupied with the details of program planning, budgetting and supervision. It will need to draw upon an independent advisory body which is able to view the whole space program in proper perspective. This is close to the original function of an Associate Committee and can be provided by the ACSR, with no change in make-up of the membership.

Another important role of the ACSR is that it acts as the Canadian national committee for COSPAR. This role too will take on increased importance when the proposed organizational changes are made. It will provide the mechanism by which the views of the working scientist are represented in international circles.

Any change in the relationship between the ACSR and the Interdepartmental Committee on Space which comes about as a result of the proposals of this study will have to await the reaction of the ICS.

It is for these reasons that no specific recommendation regarding the ACSR is made.

Planning for continuity in use of resources

The planning model:

While not all features of the planning schemes adopted by other countries are transferable to the Canadian context, the introduction of a comprehensive plan for Canadian space research will require the use of a widely-understood planning model, and some features of the NASA program planning model should be incorporated.

The important characteristic of a workable planning model is that over significant periods of time it should produce a a match between the utilization of all available manpower resources in all sectors and the available funds. Since both manpower and funds are subject to allocation decisions, there must be a close interaction between the plan and the allocation decisions, but while present allocations may affect short term plans, long-term plans clearly should affect allocations. It is only in the long term that a planning model can increase the efficiency with which a given allocation of resources will achieve progress toward program goals. The NASA organization has attained notable success in managing large-scale programs. One feature of the approach used is to eschew the allocation for indefinite periods of resources to each area or project in some proportion to its relative importance. Instead a dynamic model is used in which each experiment and each area is scheduled over a period of time, phased in and phased out, in such a way as to ensure that the research results are obtained in a sequence that is appropriate to the solution of major problems. At the same time the plan ensures, as closely as is compatible with the research objectives, the continuous use of all resources in all sectors.

For example, the provision of a new facility, such as

the balloon-launching facility recommended in this report, would be subject to evaluation of the minimum scale that would provide the necessary capability and of the maximum scale that could be regularly and frequently used by the experiments planned over several years. Adjustments in the scale of operation would be made from year to year, but it would be a poorly planned facility if the scale of the facility resulted in some worthwhile experiments being postponed indefinitely, or if the lack of experiments produced a hiatus in the operation of the facility for a year. Contrast this approach with the present rocket allocation policy which makes it extremely difficult to obtain a firm rocket allocation more than a year in advance of the launching, even though a truly innovative rocket experiment may take several years to develop to the flight stage.

Another important feature of the planning model should be adequate provision for the reduction, analysis, interpretation and publication of the results of scientific experiments. The plan is a poor one if it calls for the redeployment of people and funds immediately after the completion of an experiment and before the results have been incorporated into the body of scientific knowledge.

The foregoing remarks are fairly easily applied to the space scientist; calling only for a somewhat better defined allocation of responsibility and the introduction of the concept of scheduling of experiments. It is much more difficult to apply them to the development of space hardware. Typically a large development project progresses in a single sawtooth mode. It starts slowly but has a specific completion date and as that date approaches a large engineering development team is built up in industry and a parallel management team is built up in government. Finally, as various aspects of the project are completed the whole complement of people is released from the project in a relatively short period of time. The need to absorb these people into other projects where their skills can be utilized can cause a major crisis. The superficial

view is that accomplishment of the development in the shortest possible time is the most efficient approach. This demands a maximum build-up of personnel involved, and in the end the lack of productivity of these people, immediately after the project is completed, becomes an overhead charge against some project and hence against the Canadian taxpayer. It is probably more efficient to ensure that the development program is at a level to provide continuous utilization of skilled manpower even at the expense of slower-than-optimum rate of development on each project. All of this applies generally to the whole area of development of space hardware, not just to space research projects. The point of exploring the question here is to draw attention to the greater flexibility in scheduling that attends research projects so that with long-term planning major hardware development projects for the space research program can be used to "fill in the valleys" in other programs.

In the end, complete continuity in resource utilization is probably not compatible with the flexibility needed to bring space research back to the forefront of international science. Nevertheless, a much better job can be done than has been done. A total program of the magnitude recommended in this report would provide ample flexibility in starting, expanding, contracting or stopping individual experiments without seriously endangering the total utilization of resources. This can only be true within the context of an all-encompassing program plan.

The planning wedge:

This is the name given by the National Academy of Sciences to a subsidiary stratagem that provides a useful index of the whole attitude we are trying to convey. While the concept is simple, the disciplined thinking required for its application is certain to have a salutory effect on planning, which in the Canadian context has been so capricious as to be unworthy of designation as planning

at all. A recent publication of the NSF, Space Science Board[11] gives the definition of the "planning wedge" (italics added);

> "The planning wedge is the annual funding available for new projects. It is derived by summing (for each succeeding fiscal year) the estimated costs for the *completion* of all existing projects and subtracting the total so derived from the expected fiscal year funding for research and development. It is a wedge (with its sharp edge in the next fiscal year) because the R & D funding for space science is expected to remain constant during the near term, while the runout costs of existing projects decrease with time. Hence the funds available for new projects increase with time, as a wedge increases thickness when one moves away from the leading edge."

Not all project costs necessarily decrease with time but surely it is a healthy attitude to start by assuming that they will unless there are valid arguments advanced to show why they will not. The simple idea of using the planning wedge in program planning focusses attention on the *next* useful thing to do, and at the same time recognizes the need for finishing what is already underway.

The U.S. Space program is mature. That of Canada is not. It is unlikely that the Canadian program can achieve meaningful goals if we are to accept that "the .... funding for space science is expected to remain constant .... ". Nevertheless it is important to plan wisely, and wise planning includes a realistic acceptance of the fact that every experiment, every project has a finite productive lifetime and should be replaced in the foreseeable future by new ideas, new experiments, which continue to build on what has gone before. At the present time the Canadian space research program has built-in disincentives to innovation. It is much easier to obtain funding to continue what one is now doing than to get funding for new departures. Any planning model that incorporates incentives to maintain the *status quo* is doomed to failure. The "planning wedge"

is not a unique planning tool but whatever concept is adopted it must incorporate at least the attitude conveyed by its use.

Manpower

During the preparation of the DASP paper an attempt was made to identify the number of active scientists now involved in Aeronomy and Space Physics and the number that would be required if the total proposed program were to be implemented. The committee found 78 active space scientists in Canada of which 45 are in the universities, 32 are in government laboratories and one in the private sector. Even this is not an accurate picture of the human resources available to the field because many, perhaps a quarter of the scientists in universities and in government laboratories devote a large fraction of their time to administrative, teaching or other non-scientific duties. Nevertheless, this group undoubtedly represents the bulk of the scientific manpower now devoted to space physics research in Canada. The numbers involved in each of the other areas are difficult to determine because many (involved, for example, in meteorology, remote sensing and space astronomy) have only a small portion of their total activity in space-related research. A full-time equivalent number between 10 and 20 would probably be realistic for each of the other three major areas of space research.

The numbers arrived at above represent a significant reduction over the last few years. The superficial reasons for this reduction are fairly obvious. There has been a relative reduction in direct and support funding for space research which has discouraged a number of scientists from pursuing a research career in space science. In the government laboratories there have been shifts in emphasis that have forced a number of scientists to take up non-space-related work. Also the lack of a long-term program with clearly defined goals has persuaded a number of scientists that the probability is small of doing research of a quality that would remain competitive on the international scene. But there is a more subtle additional influence at work. Most of the present members of the space research community were attracted to the field in the period of rapid expansion after the launching of the first sputniks. These people are now at an

age when they are likely to move on to administrative posts or into less direct involvement with the day-to-day details of research. In the normal course of events they would have been replaced by younger people who, having served their apprenticeships in one of the active groups, would be able to take up positions of leadership in the field. Unfortunately the current freeze on academic and government research positions denies the younger person this opportunity. For a typical sample of the population of Canadian space scientists it was found that some 62% received their first degrees more than 15 years ago. The corresponding figure for plasma physicists is 55% and for astronomers 41%.

By actual count there has been over the last several years about fifteen new space scientists turned out by our graduate schools each year. These people are trained for space research but this training also makes them well-equipped to work in the more applied areas of technology, and in the absence of research opportunities they have gravitated to alternative employment where there has been a continuing demand. Although their talents are being effectively utilized, their absence from space research contributes to its deterioration, because not only is there likely to be a shortage of space researchers in the future, but already the field is feeling the effects of the absence of young people with their new ideas, their vigour and their enthusiasm.

The DASP paper addresses itself to this problem in somewhat different terms and recommends the institution of a research associate program. The suggestion involves the funding of about six new research associate positions in the universities for each of the next five years. While there would be some attrition this would provide a pool of about 30 new experienced researchers, distributed in age but still concentrated near the younger end of the age spectrum, from which to draw replacements for the present research leaders. The total cost of the program would not be great (estimated to be about 1.25 million over the five years), and most if not all of the people involved could reasonably expect to replace the currently active scientists in permanent positions near the end of

the five-year period so it would not be a continuing commitment much beyond that period.

The DASP proposal is an imaginative response to a very real problem. If implemented it would greatly increase the effectiveness of space research in Canada over the next ten years and beyond. Nevertheless, to propose that it be implemented as an isolated measure independent of the already recommended close interaction of the Office of Space Research and the Corporation of University Space Science would be to negate the main thrust of total program planning which is a central recommendation of the present study. As an alternative *it is recommended:*

> *That the Office of Space Research collaborate with the appropriate agencies in finding means by which a sufficient number of younger scientists*
> 01 *can be brought into the space research program, offered reasonable career prospects and given the opportunity to progress to positions of research leadership.*

There is another aspect of human resources that needs attention. Because of rapidly developing activity and accompanying shifts of emphasis much of the research expertise in the government sector exists in departments whose missions do not permit full utilization of that expertise. Mechanisms for the transfer of funds and manpower between government departments exist. Thus the funding of a research project to use specialists in one department to pursue the research objectives of another department is possible but for the individual scientist there are difficulties. Under the present arrangements, he may foresee eventual frustration in his career development if his particular talents continue to diverge from the main thrust of his department's mission. If these situations were rare, each could be addressed as an individual case but, particularly in space research, the number of scientists involved is significant, and if over-all research planning is to be implemented the number will grow rapidly. Clearly, it is important that the best available research talents should be marshalled for the attack on each new research objective as it emerges, but if the best available scientists are to be attracted to each attack the development of their careers must not

be jeopardized. These difficulties will, to a large extent, be alleviated by the existence of a governmental agency with a mission in space research. Such an agency, the Office of Space Research, has already been recommended and it should involve itself in the planning of manpower deployment for all aspects of the research program including research done in government laboratories, and should assist in the negotiation of man-year transfers where appropriate. If done against the background of a visible, long-term program it will be clear to the individual scientist that his career prospects are being adequately protected. This responsibility of the Office of Space Research is covered in a general way under the major recommendation of the preceding section (Organization) but in order to clarify and extend that recommendation, *it is recommended:*

O2 *That the Office of Space Research, through its direct liaison mechanism with individual government departments, take the initiative in arranging inter-departmental transfers of funds and manpower to concentrate the most appropriate research expertise on the achievement of each research objective. All such transfer arrangements should protect reasonable career aspirations for the scientists involved.*

Industrial Impact

Many of the implications for industry of the proposed program and the method of its organization have been pointed out earlier in this report. It remains necessary only to make a few additional remarks here, and to draw attention to the crucial interaction which is envisaged between the research program and industry.

Industry is quite properly interested in sales, and in the present context we mean sales of technologically very sophisticated equipment. Usually these equipments (such as, for example, communication satellites) are sold in very small numbers, and the buyer is interested only in a product which is demonstrably at the forefront of the current state-of-the-art. Viability in the market place depends on continuity of achievement, and this depends on a rapid continuous translation of new knowledge from research into development of new hardware. While stressed before, the need for continuity in this activity cannot be over-emphasized.

Much of the research program outlined in this study will not be accomplished without the development of new instruments. There are few other fields of research that depend so directly on the development of ever more sophisticated hardware. Unfortunately, in the past much of the required instrumentation has been developed in universities and in government laboratories where there was no clear mechanism or incentive to transfer the new designs to industry where they could have contributed to product development.

In the section entitled "Organization" it was mentioned that in a few instances where small firms were entrusted with complete responsibility for developing advanced instrumentation they were able to convert these developments into significant export sales. We must be able to do this more often. We need more direct and more effective links between the research and industrial communities. Where the magnitude of the project has required it (as in the ISIS program) Canadian scientists have worked closely and effectively with industrial development teams. This should be the usual rather than

the unusual circumstance.

The proposed research program provides ample scope for new "high-technology" developments. In planning each new project there are three alternative courses:

a) To buy the instruments from non-Canadian sources.

b) To develop the new instruments in government or university laboratories with no industrial involvement.

c) To arrange for the scientists involved to work closely with an industrial development team to produce the new instruments.

While all three courses may result in comparable instruments and while (c) may be apparently the most expensive (by the usual methods of costing) it is the only course that will produce new products, new export sales and new jobs for Canadians.

There is a growing opinion in Canada that high technology should be supported simply for the sake of its industrial benefits. How much better to support an area of research that is needed in Canada and which at the same time will provide for substantial improvement of our industrial capability! To achieve this improvement it is necessary that comprehensive planning be done by planners who are committed to involving the industrial sector. While the undiscriminating application of a "buy Canadian" policy may be unnecessarily expensive and in the long term may operate to the detriment of Canadian industry, the judicious application of the principle outlined above to procurement for the proposed space research program could contribute to sound mature growth of a viable space-oriented industrial sector in Canada.

The involvement of industry in the research program, while significant, will be small compared with its involvement in the overall program of space activity. Nevertheless the research phase is crucial because it provides experience with the most advanced instrumentation, access to the latest knowledge of the environment and of the phenomena of space and the most scope for innovation.

Another aspect of industrial involvement needs attention. An important criterion of the ability of an industry to innovate

in a technologically advanced field is the quality of its personnel. Not only must the personnel be well trained but they must be kept actively involved in the most advanced aspects of the field. Such people will from time to time wish not only to develop new instrumentation for space experiments but also to carry out space experiments. And to enable them to do so will improve the quality of the research program, improve the quality of the industry and encourage the free interchange of people between government, industry and the universities. The present program of unsolicited proposals seems to be directed primarily toward technological development, but there should be a clearly defined means by which an industrial employee can propose and carry out space experiments.

The necessary mechanism for ensuring industrial involvement in the space research program has been covered in the major recommendation for the institution of an Office of Space Research, but in order to extend that recommendation and draw attention to the particular need to involve industrial scientists in space experiments *it is recommended:*

03 *That the Office of Space Research institute a procedure by which it and other government agencies can respond to industrial proposals for space experiments. The objective of the procedure is to enable industrial employees to carry out space experiments under contract.*

Comments on Funding

When the space age began Canada was one of the first nations to perceive the benefits that could be derived from a research effort in space and was quick to divert an appropriate fraction of her resources to this new field. The scientific rocket and satellite programs were vigorous and earned for Canada a respected place in international science. The early rewards of this activity were substantial and seemed at the time to provide a firm base for future research and for the subsequent exploitation of space. But just when the stage was set to capitalize on early successes the space research activity in Canada began to be eclipsed by that of other nations who, having started more slowly, were then prepared to commit whatever resources were necessary in order to achieve a place in the international space community. In particular, while Canada's sequence of scientific satellites ended with ISIS II, other nations including some of the smaller ones are forging ahead with new scientific satellites. Without a revitalization of its research program, including the use of scientific satellites, Canada will soon lose even its present position with respect to the exploitation of space.

The logical steps by which a discussion of funding should proceed are; a) establishment of the present rate of expenditure, b) estimation of the rate of expenditure required to achieve the needed level of research activity, c) the recommendation of an orderly sequence by which the level of funding should be increased or decreased from that of a) to that of b). Unfortunately, in spite of the friendly and cooperative efforts of some of the most knowledgeable people in the government sector this study has failed to achieve any verifiably accurate estimate of the true current level of spending on space research. This is because there exist no uniform criteria for the identification of research expenditures and even where acceptable criteria exist they are rarely used to identify the total cost (including, for example, salaries and overhead). While this situation is frustrating in the present

context it is entirely consistent with the current techniques of internal government accounting and no criticism of those techniques is intended here.

Faced with this impasse, other, less desirable approaches are possible. Since other countries or groups of countries already have single agencies responsible for space activity it is reasonable to look at their expenditures as a possible guide to an acceptable level of expenditure in Canada. For example, the U.S.A. with a total population of 200 million spends about five billion dollars per year on all space activities of which three billion is for space research and development, and of that figure, about one billion is for space research. Japan's expenditures are expanding rapidly. In 1975, with a population of 100 million, it is spending about 190 million dollars on all space activities. The European Space Agency, which serves a total population of about 200 million, is now spending at the rate of 500 million dollars per year but the individual countries also spend substantial sums of their own national programs, and current individual figures for their expenditures are not available. In each case the expenditure for research appears to be about 20% of the total space expenditure. For the United Kingdom the total expenditure on space activities, including a contribution of about 55 million to ESA, is about 120 million dollars (for a population of 56 million) and the space research fraction of this total expenditure appears to be in excess of 30%.

The best available figures for Canada seem to be those of Statistics Canada. These figures suggest that Canada spends about 63¢ per capita per year on space science. The figures quoted above suggest that the corresponding expenditure is about $5 in the U.S.A., 38¢ in Japan, $1 in the European community and 65¢ in the United Kingdom. The case has been made earlier that Canada has a much more clearly apparent need for the utilization of space than other countries. The relevance of space to the national interest is more directly related to the physical size of a country than to its population. Consequently Canada should spend relatively more on a per capita basis than do other countries. Since Canada's place in

space research has deteriorated and needs positive action to restore it, a somewhat larger portion of the total expenditure in Canada should be directed toward research. While this line of argument may be helpful it falls short of a definitive recommendation.

The Office of Space Research will need to come to grips with this problem, but it must be recognized that even with comprehensive planning it may still not be possible or desirable to arrive at an overall global figure for the total real cost of the space research program. Many of the research activities will continue to be so closely integrated with non-research activities that no meaningful separation can be effected. Nor is such a separation necessary. The objective of the Office of Space Research will be to implement the research program and in doing so it should not be diverted by a requirement to draw precise lines between expenditures for research and expenditures for the development of new or improved technology. What it must do is to estimate accurately the incremental costs associated with those additional activities that are necessary to implement the program. Some of the proposed program is already funded through existing agencies, much of it can be supported by the reallocation of current funding. Again, no specific recommendation is necessary because this responsibility is already covered by the major recommendation concerning the Office of Space Research.

An effort has been made to estimate the cost of the proposed program in relation to the present level of effort. The results of this assessment are given in Appendix I. A major constituent of the program is the proposal for new scientific satellites. There are at the present time no firm plans for future scientific satellites in Canada, and satellites are needed. But first it is useful to look at the change in effort implied by the non-satellite portion of the program. Reliable estimation in this area is particularly difficult and comparison with the available figures from other nations is not helpful. The program being proposed for Canada includes a substantial component consisting of ground-based observations. While other nations support comparable programs of ground-based research the expenditures involved are not normally

included under space activities. Then, too, there is an uncertainty surrounding the proposed northern operations. The research program calls for specific activity at high latitude stations. In the past scientific research at northern stations has been largely dependent upon the provision of accomodation and facilities by the operating agency to the visiting scientist at little or no cost. Northern radar stations have been used extensively for this purpose but in the future they may not be available. In spite of these uncertainties research in the North is necessary to the space program and must be included. To neglect this important aspect of research in Canada simply because it is expensive would be unthinkable. In any case some increased level of activity will be required to implement the non-satellite portion of the program but the increase is not large. Given the apparent willingness of all parts of the scientific community to re-orient their research objectives an acceptable rate of implementation could be achieved by increasing the funding level by some 25%. Nor should this increase be uniform through all sectors. In particular the university sector needs special attention and presumably would receive it through the mechanisms already proposed. It is worth noting that although more than half the space scientists are in universities the visible research expenditures in universities make up no more than a tenth of the total. Such comparisons are complicated by the fact that neither university faculty salaries nor overhead costs are included, but some salaries are included. In the available governmental figures apparently no salaries are included. Nevertheless it is obvious that the university community is underutilized in the prosecution of the present research activity and represents a substantial additional human resource that can be used to implement the proposed program. To make optimum use of this resource would be one of the objectives of the recommended association of universities.

With regard to scientific satellites it is a little easier to estimate the impact and to recommend a level of activity. The construction and launching of a small scientific satellite can be expected to cost between 15 and 20 million dollars and an acceptable

program would utilize about three scientific satellites over a period of ten years. A reasonable rate of expenditure on scientific satellites over an extended period would be about 5 million per year. This, of course, should not be regarded as a fixed rate of expenditure. As was indicated in the section under "Planning" the preferred strategy is to use the construction of scientific satellites to "fill in the valleys" in the total program of industrial space related activity. This might lead to spasmodic expenditures at rates considerably above the long term mean but as long as this resulted in about three satellites over the ten year period it would be compatible with the research objectives. Nor should the requirement for adequate *utilization* of the satellite be neglected. To use the satellite after it is in orbit requires much less manpower and much less expenditure than are required to construct it but unless adequate provisions are made for the operation of the satellite and for the interpretation of the data all scientific benefit is lost. This may seem an obvious admonition but the tragic truth is that it has often been disregarded in the past.

In summary then, a sequence of scientific satellites should be included in the program plan and the average rate of expenditure on the construction and launching of new scientific satellites should be about 5 million per year. Each satellite will also require the expenditure of a small fraction of this amount (or the equivalent in man-years) for its effective utilization. The actual additional funding required for implementation of the remainder of the research program will not be known until detailed evaluation has been carried out by the Office of Space Research but it appears that an increase of about 25% over the present level of funding in the context of a new overall research plan would be sufficient to give Canada the effective space research program that it needs.

In space research as in so many human activities there is a threshold effect. Over the last few years space research has been ineffective in Canada largely because of fragmentation but, too, the level of support has been marginally less than that required for an effective program. In the future if we ensure that the level

of support is at least marginally greater than the critical value the return in useful research results will be out of all proportion to the difference between these two levels of support.

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Briefs prepared for this Study

a. Report on Cosmic Rays — D. Venkatesan

b. The priority project for Canadian Space Research — G. Rostoker & J.V. Olson

Appendix I

Assessment of the financial implications of the recommendations

Major Recommendation

M1 - The setting up of an Office of Space Research would require the appointment of a Director and a small staff for the planning and coordinating functions. The total staff for this function might be two in 1976 rising to a continuing level of about 10 in 1979. The actual annual cost (within NRC) of the Office of Space Research would rise over a period of five years to about $250,000.

For the operation of the group facilities under M1 (d) most of the appropriate staff already exists in the Space Research Facilities Branch of NRC. The implementation of new programs may require additional staff the cost of which is included in the program and facilities estimates which follow.

Organizational Recommendations

O1, O2, O3 } Included in the Office of Space Research

Recommendations for Facilities

F1 - As outlined earlier the scientific satellite program should be reactivated at approximately its former level. This would require continuing expenditures at the average rate of about 5 million per year.

F2 - It appears likely that the campaign stations could be financed (over a time-span of three to five years) within the current and projected budget for the NRC's Space Research Facilities Branch provided its activities were re-organized along the lines suggested.

F3 - As indicated earlier the provision of a limited array of data platforms would be costly if done in isolation. If done in conjunction with a comprehensive array of data platforms to be used by operating agencies the costs assignable to the space science component would be of the order of a $100,000 per year.

F4 - The suggested scale of balloon launching facilities is a modest extension of developments already planned within the Space Research Facilities Branch.

Program Recommendations

National Programs

NP1 - The suggested campaign activities are intended to represent a re-orientation of research strategy. The incremental costs involved are largely associated with the higher costs of northern operations, and will be influenced to a large degree by the choice of sites and the presence of existing accommodation for living and working at those sites. (See assessment below for NP3)

NP2 - The exploitation of satellite retro-reflectors, given the existence of suitable satellites, could be accomplished largely by the coordination and re-direction of relevant existing programs in various government departments and industries.

NP3 - The provision of the suggested number of rockets represents an increase over present level of activity but is a substantially lower level than that achieved in former years. Concentration of the rocket firings within limited periods (during campaigns) would result in some economies. In all, the rocket and campaign activity suggested represents a gradual increase of funding over about five years to a level of about one million dollars above the present annual level, of which a large part would be for the provision of payloads.

NP4 - The major new costs of the balloon program would be included in the facilities provided under F(4). The increased level of research activity engendered by the existence of that facility would probably require annual funding at the level of $250,000 - $500,000. These costs would be shared by several government agencies and industrial firms.

NP5 -
NP6 - The nature and extent of the increased activity suggested by these two recommendations (for the utilization of remotely-sensed atmospheric data and for studies of atmospheric pollutants) would be determined and presumably funded by the Dept. of the Environment.

NP7 - While it is important that the universities become involved in the education of remote-sensing researchers, no increased funding is envisaged.

NP8 - The recommendation that a specific plan including timetable be defined for remote-sensing research activities, represents only an endorsement of plans that already are being developed.

International Programs

Canada's involvement in International Space Programs will require continuing negotiations. Recommendation M1 (f) proposes the introduction of a mechanism for such involvement and funds will be necessary to support this activity.

Subject to the appearance of promising opportunities for international cooperative programs funds amounting to $500,000 per year may eventually be required for this purpose. Larger expenditures for space hardware should properly compete with satellite program funds.

IP1 - The recommendation here is to define the actual nature and extent of involvement in the shuttle research program. A specific plan might well reduce the costs below those that could be incurred in the absence of such a plan.

IP2 - Bilateral agreements for the use of space telescopes may require funds but if successful the negotiations should result in the expenditure of these funds in Canadian industry. The magnitude of the program cannot be defined in the absence of specific proposals.

IP3 - The bilateral agreements relating to medical research are subject to the same constraints as those suggested under IP2.

Study Recommendations

S1 to S6

While the funding of each of these studies would require only modest sums, the studies may result in recommendations for significant expenditures. However, it would be inappropriate to anticipate the results of the studies by estimating the magnitude of the implied funding here.

In total then, while several recommendations may lead eventually to further increases in expenditures, the presently identifiable requirements, when fully implemented, amount to annual additional expenditures of 5 million dollars for satellites, 1 million for rockets and about 1.5 million for the remainder.

Appendix II

Description of the Study

This study represents the confluence of a number of separate activities begun during 1974 and 1975. The Associate Committee on Space Research held discussions regarding the need for a somewhat clearer picture than then existed of the future of space research in Canada. During the same period the Inter-departmental Committee on Space took note of the impending hiatus in the utilization of scientific satellites in the space program, and asked the ACSR (which functions also as a scientific advisory committee to the ICS) to carry out a study with a view to recommending a space research program for Canada. At the same time the Division of Aeronomy and Space Physics of the Canadian Association of Physicists had decided independently to prepare a paper outlining the future of aeronomy and space physics. These various initiatives came together in May 1975 when the National Research Council agreed to sponsor the ACSR paper and the DASP paper. The latter was regarded as an essential input to the former. Accordingly it was decided to proceed with the preparation of a paper under the following conditions:

In order to be useful the paper was needed in draft form for discussion by the ACSR by 1 November 1975, and for final submission by the end of 1975. The very short period available for preparation precluded the use of extensive polling methods and of compilation of descriptive data concerning the present activity. It was also considered expedient to assign responsibility for the preparation of the paper to a single author who could make use of various colleagues in collecting suggestions regarding the research program. A steering committee was also named to guide the study as it progressed. The names of the colleagues who assisted with the collection of information and of the members of the steering committee appear on the title page of the report.

The guidelines for the paper were stated as follows:

"The paper is to cover:

a) Identification of important areas of space research:

(i) Aeronomy and space physics

(ii) Astronomy

(iii) Other disciplines, such as meteorology, remote sensing, life sciences, etc.

b) Trends in space research internationally and a Canadian Program in international context;

c) The case for space research in Canada;

d) The organization for space research in Canada;

e) A space research program for Canada, including, for example, budget, priorities, how to get started, etc."

As a result of the temporal constraints it was agreed that the report should make no attempt to catalogue present research activity. Present work was to be alluded to only with reference to the future. A similar approach was to be taken with respect to industrial capabilities. Quite adequate surveys of both of these areas already exist.[1,2]

It also was clearly impossible to evaluate all of the suggestions for future research in detail. Fortunately as the collection of information progressed it became clear that the details of particular experiments were not crucial to the main theme of the report. That theme, which reflects a widespread concern among the space science community, is that we desperately need a coherent, balanced plan for space research over the next ten years.

In addition to the DASP paper and a number of special written submissions, visits were made to collect information for the report. The subject matter of the report was discussed with some 100 people. Since the visits were all made during the summer holiday season it was inevitable that some key people were unavailable but in spite of this, the remarkably clear consensus that emerged from the discussions makes it highly unlikely that the presence of the missing people would have changed significantly the general conclusions.

In the visits not all groups in each sector could be included. Within the time available it was possible to visit only

5 government laboratories

8 universities (another two were represented at the meetings)

6 industrial firms

but some of these were visited more than once.

Conversations were also held with a number of government officials and individuals in universities and in industry. Four meetings of the Steering Committee were held.

Visits, discussions and submissions

Visits

by the author and D.J. McEwen

Herzberg Institute of the National Research Council

Communications Research Centre of the Dept. of Communications

by the author and G.G. Shepherd

Bristol Aerospace Ltd.

Barringer Research Ltd.

RCA Ltd. (Montreal)

SPAR Aerospace Ltd.

SED Systems Ltd.

by the author and T.R. Hartz

University of Western Ontario

York University

University of Saskatchewan

University of Calgary

University of Alberta

University of British Columbia

University of Victoria

MDA Associates

by the author

Canada Centre for Remote Sensing of the Dept. of Energy Mines and Resources

Atmospheric Environment Service of the Dept. of the Environment

Institute of Ocean Sciences of the Dept. of the Environment

Communications Canada (J.H. Chapman)

Telesat Canada (R.F. Chinnick)

Dept. of Industry Trade and Commerce (J.H. Crysdale)

University of Guelph

Dr. G.H. Embree

University of Toronto Inst. of Aerospace Studies (J.H.deLeeuw)

Discussions

were held with the following people, in groups or individually in person or by telephone.

G. Atkinson
W.M. Auld
M.P. Bachynski
A.R. Barringer
R.E. Barrington
N. Basco
J.S. Belrose
C. Bland
G.V. Bull
J.R. Burrows
J.G. Chambers
J.H. Chapman
R. Chinnick
W.L. Clink
L.L. Cogger
J.H. Crysdale
W.A. Cumming
B.W. Currie
J.A. Davies
J.H. DeLeeuw
J.W. Doan
W. Dorley
G.H. Embree
W.J.F. Evans
F.R.C. Ezemenari
A. Falconer
A.W. Fia
B. French
J.A. Fulford
J.F.R. Gower
J.B. Gregory
E. Grinshaw
H.P. Gush
G. den Hartog
T.R. Hartz
R. Hawkes
M. Hodson
R.E. Horita
E.J. Llewellyn
S. Jeffers
D. Johnson
A. Vallance Jones
T. Kakashima
A. Kavadas
H. Kerr
J.D. Keys
C.Y. Kim
J. Kruus
C. Lennox
R.P. Lowe
G.F. Lyon
J.S. MacDonald
J.S. MacDowall
C.L. Mateer
T. Mathews
G. Melville-Jones
J. Miller
R. Montalbetti
D.R. Moorcroft
L.W. Morley
E.G. Morrissey
J.D. Morton
L. Myers
R. McAughern
D.R. McDiarmid
I.B. McDiarmid
D.J. McEwen
P. McIntyre
A.G. McNamara
R.W. Nicholls
G.R. Nourry
J. Olson
F.J.F. Osborne
S. Peteherych
C.R. Purton
K. Ronald
O. Roscoe
G. Rostoker
H.I. Schiff
W.G. Schneider
S. Screenivasan
R. Sharma
G.G. Shepherd
W.L.H. Shuter
I.P.W. Sinclair
D.E. Smylie
G.J. Sofko
J.M. Stewart
H.M. Sullivan
C.I. Taggart
B. Thompson
D. Venkatesan
K.K. Vij
G.A.H. Walker
D.I. Wardle
E.S. Warren
B.A. Whalen
E.J. Williamson
B.G. Wilson
R. Woods
H. Zwick

Submissions

were received from

B.G. Wilson

B.W. Currie

G.V. Bull

G.H. Embree

G. Melville-Jones

G. Rostoker (brief b.)

D. Venkatesan (brief a.)

H.J. Duffus

R.W. Nicholls

E.G. Morrissey

A. Vallance Jones, the DASP paper (companion document)

References

1. "Space and upper atmosphere programs in Canada, 1974"
William H. Waters SRFB 090, January 1975.

2. "A feasibility study on the design and fabrication of a commercial communications satellite in Canada"
Report sponsored by Air Industries Association of Canada Ltd. for Dept. of Industry Trade and Commerce, 1975.

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