PROCEEDINGS OF WORKSHOP
ON
MATERIALS PROCESSING IN SPACE

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CONSULTANTS TO INDUSTRY AND GOVERNMENTS

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PREFACE

The opportunity to perform experiments in microgravity provided by the United States Space Shuttle has opened up a new area of investigation for Canadian and other scientists. Some countries have already made significant investments in microgravity studies using this facility. Canada has participated to a modest extent, largely through cooperative arrangements with scientists in the US or direct involvement in NASA programs. Only recently have steps been taken to make Shuttle facilities available to the Canadian community on a competitive basis; Canada is just starting up a very expensive learning curve.

The Canadian metallurgical (including semiconductor) community has been aware of the opportunities for some time, but the possibility of a national decision to join in the Space Station Program has spurred efforts to identify commercial interests, and industry has responded with several proposals to undertake proprietary studies. The possibility of blending academic and industrial interests led to a suggestion that the time was right to bring together representatives of industry, academe and government to share experiences and views on the value of microgravity studies. These Proceedings record the presentations made at the resulting Workshop, along with short summaries of the deliberations that took place in four theme discussions.

In order to focus interest, and to limit the size of the workshop, it was decided to include only the metallurgical and semiconductor fields. The program was established to provide formal presentations and syndicate discussions, with the objective of presenting a snapshot of the current situation as it relates to Canadian interests. Attendance was by invitation, with representation from the three Canadian sectors and NASA, the latter to provide an overview of the US experience. A list of participants is included in Appendix I.

The Workshop program follows and the presentations occur in the order in which they were given. Reports of the discussions that took place in the individual syndicates are included following the formal presentations.

The Workshop was sponsored by the Department of Metallurgy and Materials Science, University of Toronto and the Department of Metallurgical Engineering, Queen's University. Financial support from the National Research Council of Canada is gratefully acknowledged. Philip A. Lapp Limited provided organizational services.

MATERIALS PROCESSING IN SPACE
WORKSHOP PROGRAM

Monday, October 21, 1985

6:00 p.m.	Peel Room, Host Bar	
6:30 p.m.	Dinner - Peel Room	

Session 1 - Chairman: R. C. Tennyson - Peel Room

8:00 p.m.	Opening Remarks	Rod Tennyson
	Canadian Program	Karl Doetsch
	NASA MPS Program	Roger Crouch
	NASA Spacelab	Tony England
	NASA Space Commercialization	Isaac Gillam

Tuesday, October 22, 1985

7:00 a.m.	Breakfast - Guild Hall B	

Session 2 - Chairman: W. A. Miller - Guild Hall C

8:30 a.m.	Canadian Astronaut Program	Steve MacLean
	Cominco	Brent Bollong
	Queen's Program	Reg Smith
	Honeywell-Noranda	Blake Reid
	MPB Technologies	Gilles Saintonge
	Coffee	
	BM Hi-Tech Inc.	Eswar Prasad
	Canada Centre for Space Science	Roy VanKoughnett
	Chemical Metallurgical Processing in Space	Ben Alcock
	Preparing Experiments for Space	Rod Tennyson
12:30	Lunch - Guild Hall B	

Session 3 - Chairman: J. D. Keys

2:00 - 4:30	Syndicates	

Rod Tennyson
University of Toronto

Opening Remarks:

This symposium is sponsored by the National Research Council of Canada. We're dealing, tomorrow, with non-biological materials, so we're not going to hear any talks about electrophoretic separation. I should tell you that all sessions are being taped, including this evening. In thanking NRC for sponsoring this symposium, I'd like to particularly thank Dr. Karl Doetsch for the efforts he's made on our behalf in providing the support to run this symposium.

The program has been organized by Dr. John Keys, who has put a lot of effort behind the scenes on the detail organization, the inviting of speakers, and generally making sure that the university people do their work. He has asked me also to mention that he was helped in organizing this symposium by the University of Toronto, particularly Al Miller who is unable to be with us tonight, and by Professor Reg Smith from Queen's University.

Now I would like to introduce to you, the head table and express my appreciation to our U.S. visitors from NASA who have taken time out to come here and talk to us this evening, to give us some idea of what's being done in the space processing field. The intention is that through cooperative efforts between Canadian industry, government and university people, we should be able to put together by tomorrow night, an overview of what experiments could be contemplated in a Canadian program in this area.

The people who have come to be with us tonight include, as I mentioned earlier, Dr. Karl Doetsch, Associate Director of the National Aeronautical Establishment with the National Research Council. He is also head of the Space Station and Canadian Astronaut Program. We have Roger Crouch, Chief Scientist of the Microgravity Sciences and Applications Program at NASA headquarters in Washington.

We also have Dr. Tony England, a NASA astronaut. He actually flew on Spacelab-2 mission in July of '85; we're glad to have you with us as well, Tony. We also have Mr. Isaac Gillam who's the Assistant Administrator for Commercial Programs at NASA.

Ladies and Gentlemen, this is your head table. I did mention earlier, of course, Dr. John Keys, Dr. Reg Smith and Professor George Weatherly (sitting in for Al Miller) representing university and industry interest here. Now the four speakers are going to provide for us an overview on space processing, as viewed by NASA. We in Canada have to make a decision at the Government level. We know that there's been a proposal submitted on space initiative to the Government in fact we have one of the co-authors of that proposal, Professor Geraldine Kenny-

Wallace. The Government is going to meet in the next few months to make some decision on where Canada should be going in the space program. We are all well aware of our satellite program, the RMS program and what we have to look forward to in the future is the space station, as a permanent Canadian presence in space in the form of a laboratory.

Consistant with such a laboratory would be space made available, not only to the space scientists, but also to industrial people who would like to avail themselves of the microgravity high vacuum environment for developing proprietary processes. The group we have here tonight will, I hope, come up with some proposals that make sense both from a scientific and commercial viewpoint, that will help the Government determine whether we in fact should be going into space. This would be an added attribute that could support the space station laboratory concept.

I think it's obvious when you look at the direction that Japan is going and the Europeans, as well as the Americans, that Canada has to look to space station and a long term future as a presence in space. I hope that this particular group can make a case, admittedly in a very short period of time, that this is a wise move for Canada to make. We must be very careful that we don't try to oversell the program in the sense that we, with our enthusiasm, convince politicians and others that the payoffs are going to come sooner than in fact they really are. There's an awful lot of space science that can be done and as far as a commercial payoff is concerned, that may well take a long time. Overselling a program can in the long run be dangerous.

Now, with that brief introduction, I would like to ask our first speaker, Dr. Karl Doetsch from the National Aeronautical Establishment, to give U.S. a brief presentation on the Canadian program.

edited by Amanda J. Brown

transcribed by Pippa Wysong

AN OVERVIEW OF
CANADIAN TECHNOLOGY FOR SPACE STATION

by

K.H. Doetsch
National Aeronautical Establishment
National Research Council of Canada

AN OVERVIEW OF CANADIAN TECHNOLOGY FOR SPACE STATION

K.H. DOETSCH
National Aeronautical Establishment
National Research Council Canada

ABSTRACT

Canada has agreed to participate with the USA, Europe and Japan in Phase B of the development of Space Station.

The paper addresses the preliminary studies which have already been completed concerning potential Canadian users of, and suppliers to, the space station infrastructure. Plans during the present phase include studies of an Integrated Servicing and Test Facility, Solar Arrays and a Remote Sensing Facility which could be provided by Canada to the infrastructure, and a Canadian User Development Program.

The requirements for on-orbit servicing and testing of satellites and the role, in this function, both of humans and of the autonomous systems which may be used for servicing satellites remotely from the space station, provide new technological challenges. The requirements which can be satisfied to meet broad user demands through an unpressurized, integrated servicing and test facility controlled by the crew, either from a pressurized work station or during extravehicular activity, are addressed.

RÉSUMÉ

Le Canada a accepté de participer avec les États-Unis, l'Europe et le Japon à la phase B du développement de la Station spatiale.

Le présent mémoire traite des études préliminaires, lesquelles sont déjà complétées, qui portaient sur les éventuels utilisateurs et fournisseurs canadiens de l'infrastructure de la station spatiale. Au cours de la phase actuelle, on projette de mener une étude de développement axé sur l'utilisateur canadien, de même que des études sur une installation de services et d'essais intégrés, sur des panneaux solaires et sur une installation de télédétection qui pourraient tous être fournis par le Canada en guise de sa contribution à l'infrastructure.

Les conditions requises pour l'entretien, la réparation et l'essai en orbite des satellites et le rôle, à cet égard, tant des humans que des systèmes autonomes qui pourraient servir à assurer les services nécessaires aux satellites à une distance éloignée de la station spatiale, représentent de nouveaux défis technologiques de taille. On étudie les moyens qu'il est possible de mettre en oeuvre pour répondre aux besoins généraux des utilisateurs en faisant appel à une installation de services et d'essais intégrés controllée par l'équipage, à partir d'un poste de travail pressurisé ou au cours d'activité extravéhiculaire.

BACKGROUND

Consideration of the role that Canada might play in the development of an international space station commenced in 1982 when the development of the CANADARM, the remote manipulator system for the space shuttle, had been completed. The National Research Council of Canada initiated at that time a series of studies to identify how Canada might contribute to space station and best make use of it.

Potential Canadian uses were identified in all of the established space application areas (communications, remote sensing, materials processing, science, technology and life sciences). To support these, the most important facilities of a new space station infrastructure were found to be a manned research and development laboratory for science and technology, and a polar platform for remote sensing.

Canadian space hardware manufacturers were also surveyed to identify those subsystems which might be provided by Canada to the infrastructure. The principal areas recommended for participation were construction and servicing subsystems, solar arrays and remote sensing facilities in polar orbit.

The arrangements to study Canada's role on space station during Phase B were formalized with NASA in March 1985 and, since that time, Canada has been participating in the definition of space station systems and its missions and operations.

Canada's interest in participation is in no small measure due to the recognition that the space station infrastructure will dominate future space advances and that opportunities will arise to develop systems requiring advances in emerging technologies which have considerable spin-off potential, such as, for example, in automation and robotics. Space station has the potential of providing a good vehicle for Canadian users and manufacturers and of developing further Canada's involvement in manned space flight. Moreover, certain aspects of the Canadian space program in communications, remote sensing and science could be significantly affected by the availability of a space station infrastructure during the 1990's and beyond. Table 1 summarizes the key functions of the space station infrastructure and the potential areas of interest to Canada, both as a user and as a supplier.

TABLE 1

POTENTIAL AREAS OF CANADIAN PARTICIPATION IN SPACE STATION

FUNCTIONS OF SPACE STATION	CANADA USER	CANADA SUPPLIER
o LABORATORY IN SPACE FOR SCIENCE AND TECHNOLOGY	*	
o PERMANENT OBSERVATORY FOR EARTH AND UNIVERSE	*	*
o TRANSPORTATION NODE FOR PAYLOADS AND VEHICLES	*	
o SERVICING FACILITY FOR MAINTENANCE, REPAIR AND REFURBISHMENT	*	*
o ASSEMBLY FACILITY FOR LARGE SPACE STRUCTURES AND SYSTEMS	*	*
o MANUFACTURING FACILITY	*	*
o STORAGE DEPOT		
o STAGING BASE FOR FUTURE MANNED MISSIONS TO THE MOON, MARS, GEOSYNCHRONOUS ORBIT, AND FOR UNMANNED PLANETARY PROBES		

SPACE STATION TECHNOLOGY - CANADA AS A SYSTEM SUPPLIER

The areas found to be promising for potential participation by Canada as a supplier are addressed in the following.

CONSTRUCTION AND SERVICING

On-orbit construction and servicing capabilities, including those for the initial space station construction, will play a central role in space-based operations of the future. The availability of such capabilities could significantly affect future spacecraft system designs.

Construction and servicing is taken to include that which is required for the space station and its payloads, space platforms and other spacecraft. Many elements of the infrastructure (Figure 1), such as space station, the space transportation system, orbital maneuvering vehicles (OMV's) and orbital transfer vehicles (OTV's), will need to be used in a complementary manner to satisfy user needs effectively and efficiently. It will be necessary to design supporting subsystems so that, if possible, they possess multi-purpose and evolutionary capabilities to avoid rapid obsolescence when some phase of activity, such as the initial construction of space station, has been completed. A case in point is the space station manipulator which, during its lifetime, will need to handle a wide variety of tasks ranging from the construction of the space station itself to, for example, the retrieval and manipulation of OMV's or the transportation of a small payload of the station from one area to another for servicing.

Detailed analyses of the construction and servicing tasks required on space station were undertaken. These tasks ranged from the construction activities associated with the building of space station itself, including transportation of crew and equipment to and from the work site; the servicing of space station including the regular changeout of logistics modules and the transfer of supplies and equipment to and from the orbiter; maneuvering, deploying and capturing orbital transfer and maneuvering vehicles; spacecraft servicing; transfer vehicle servicing; and the assembly of structures on space station. It soon became clear that the diverse nature of the tasks would require, for their accomplishment, many different systems (Figure 2). This led to considerations as to the best configuration and grouping of the servicing and construction equipment, its mobility and finally its design to allow for its efficient operation by the astronauts. Further details on the Canadian analyses are provided in Reference 1.

A conceptual approach for space station servicing that has resulted from the Canadian studies seeks to centralize many of the servicing functions on an Integrated Servicing and Test Facility (ISTF). This facility would be the servicing and test centre for the space station itself, spacecraft, OMV's and large structures, mechanisms and certain experimental facilities. It would have provisions for assembly, storage of spares, and possibly for refueling (depending on safety and contamination constraints). Its mobile manipulator would allow construction, handling and servicing tasks to be undertaken at other locations on the space station. The robotic servicer would be used for the servicing, refurbishment, repair and handling of satellites and payloads, either directly from the facility, or from the mobile manipulator or potentially from the OMV's as their 'smart' front end. Finally, the facility would provide the capability to support tests for science and technology applications. Provision would be made on the facility for the appropriate power and thermal control and positioning devices to handle the servicing demands of large spacecraft.

The facility is depicted in a typical operational scenario in Figure 3 and in relation to the rest of space station in Figure 4. Control would be effected by the astronauts from both inside the pressurized modules and from an external control station. Care would be exercised to incorporate the appropriate level of automation and robotics to effect the proper symbiosis between man and machine. The tasks identified for crew participation by the potential users of space station place very significant demands on the crew's time. It is thus important that the servicing facility be designed to allow the crew to concentrate on those things humans do best, the exercise of judgment, decision making and responding to the unexpected, rather than having the crew carry out tasks well suited to automatic completion by machines. In addition, because of the significant time it takes to prepare crews for extravehicular tasks, it is advantageous to control as many operations as possible from the shirt-sleeve environment of the pressurized work station. The location of the facility in direct view of the work station would aid the efficiency of servicing operations. The design would also allow the incorporation of evolving technologies both at the task management level and in the development of more capable robots. An example of the latter would be the robotic servicer shown in concept in Figure 5 which will incorporate recent advances in robotics including machine vision, dextrous operations and both autonomous and remote control. The necessary ground support systems will be established, although one of the design goals is to achieve as much on-orbit autonomy as possible.

REMOTE SENSING

Considerable interest exists in Canada for the utilization of the space environment for the remote sensing of solar, stellar and earth phenomena. Canada is presently evaluating the relationship of RADARSAT, which is being developed as an earth observation satellite, to the space station infrastructure where it might be considered as an early, serviceable and small polar orbiting platform. As well, consideration is being given to a remote sensing facility which could be attached to a larger polar platform.

RADARSAT will comprise an instrument complement of a high resolution, steerable, synthetic aperture radar; a scatterometer; a very high resolution radiometer; and a multilinear array sensor. Its sun synchronous orbit will be at an altitude of 1000 km with a 16-day repeat cycle. Ground processing of data is envisaged.

The remote sensing facility would comprise the next generation of some of the instruments required for earth observations and would provide for on-orbit data processing to diminish the need for the very high data rates required during communication between the platform and the earth receiving stations when uncompressed or unfiltered raw, high-resolution data needs to be transmitted.

In both cases, the designs would make provisions for on-orbit servicing and changeout of modules, using elements of the space station infrastructure.

SOLAR ARRAYS

The space station infrastructure will require considerable power for its operation; the manned station will need in the order of 75 to 300kw and the platforms in the range of 5 to 25kw. This increase in the power levels from that required by the majority of present satellites will demand innovations in solar power generation, for example, new concepts for solar dynamic energy conversion systems, as well as for photovoltaic systems of the high concentration gaAs cell type would need development. In addition, power conditioning and distribution systems will demand the incorporation of new methods to allow for the high power levels, large thermal loads and long operational lifetime required by space station and the platforms.

Canadian industry is giving active consideration to the development of systems in the power range from 5 to 25kw for use on space platforms as the prime power source and on space station as auxiliary or emergency power sources.

SPACE STATION TECHNOLOGY - CANADA AS AN INFRASTRUCTURE USER

The results of the Canadian user studies have previously been summarized in Reference 2. At the time of these studies, potential Canadian users of the space station infrastructure were identified in all of the traditional space application areas. It was found that the general enhancement of the infrastructure through the provision of new elements would be of benefit to a large segment of current users and would provide new users with opportunities for product development or the gathering of information, which are presently not available. A number of missions for space station have been identified from the Canadian users' studies and these form the basis of the present Canadian user requirements in the space station mission requirements data base.

Since these studies, emphasis has been placed in Canada on developing potential users in the materials processing area. The program seeks to provide for various studies into processes which could lead to the commercial exploitation of space; for the development of multi-user but single function facilities for materials processing; for technology development; and for joint endeavour activity between government and industry to encourage the use of the space environment. A number of studies are under way which will lead to pilot experiments on the space shuttle prior to the advent of the space station infrastructure. Because it is not only the technology but also the science which is in its infancy in the field of material processes under the conditions of microgravity, the university and government laboratories are playing an important role in the development of this embryonic field.

CONCLUDING COMMENTS

The Canadian studies on space station which were initiated in 1982 and which have led to formal cooperation between Canada and the USA for Phase B of the space station development, clearly indicate not only the challenge of the task ahead, to develop and use effectively the space station infrastructure, but also the significant benefits of doing so. Opportunities will arise for suppliers of the infrastructure to develop systems which require significant technological advances with wide ramifications for application in other fields, as well as for users of the infrastructure who will be able to develop new expertise that will enhance fundamental knowledge and lead to the commercial exploitation of space.

For Canada, as a supplier, the area which has been chosen for focus, in the near term, is the development of a facility on space station for assembly, servicing and testing, which evolves from the technology developed for Canadarm, the remote manipulator system of the space shuttle. Consideration is also being given to the development of solar arrays and a remote sensing facility. As a potential user, Canada's immediate interest revolves around materials processing in space, remote sensing from space and technology development in space.

ACKNOWLEDGEMENTS

The contributions by the Canadian user and manufacturing sectors, by colleagues at the National Research Council of Canada, in particular Dr. Parvez Kumar, by SPAR Aerospace Ltd. and Philip A. Lapp and Associates, in obtaining data herein reported, are gratefully acknowledged.

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D.M. Gossain, S.S. Sachdev, P. Kumar, J.A. Middleton IAF 85- 1985

Ref. 2 - Space Station - A Canadian Perspective, K.H. Doetsch, IAF 83-35, 1983

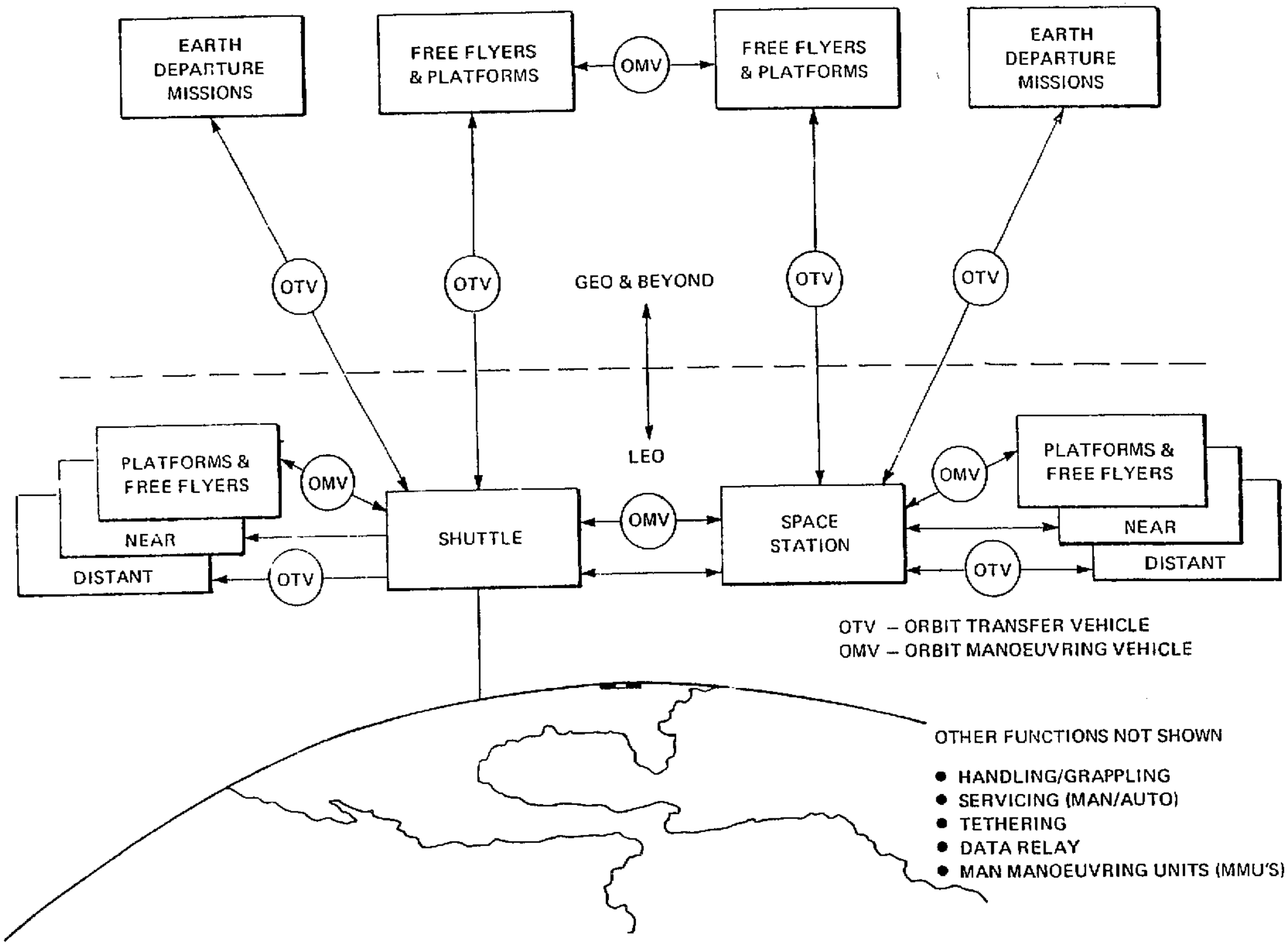


FIGURE 1: ELEMENTS OF SPACE INFRASTRUCTURE

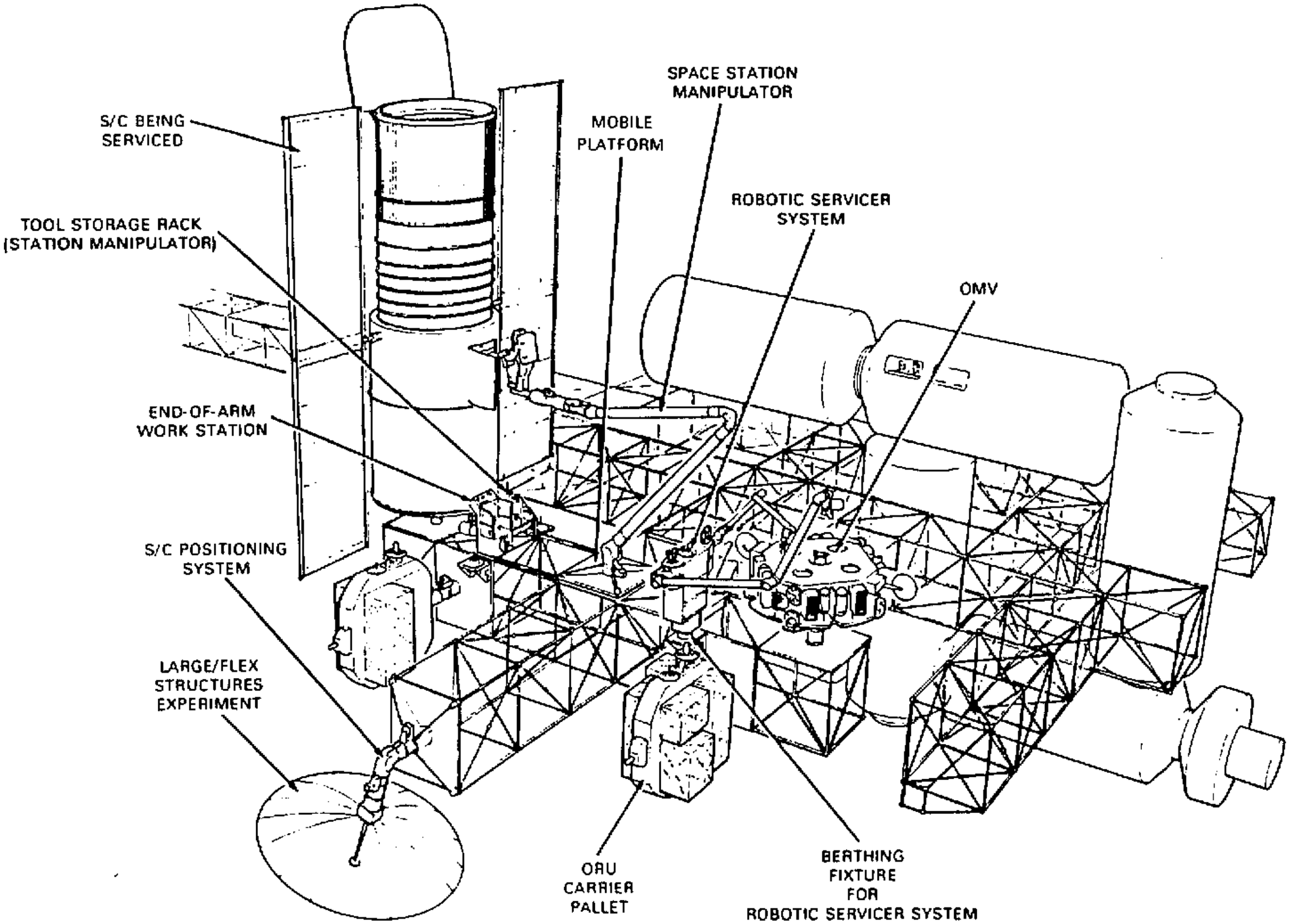


FIGURE 3: CANADIAN INTEGRATED SERVICING AND TEST FACILITY CONCEPT

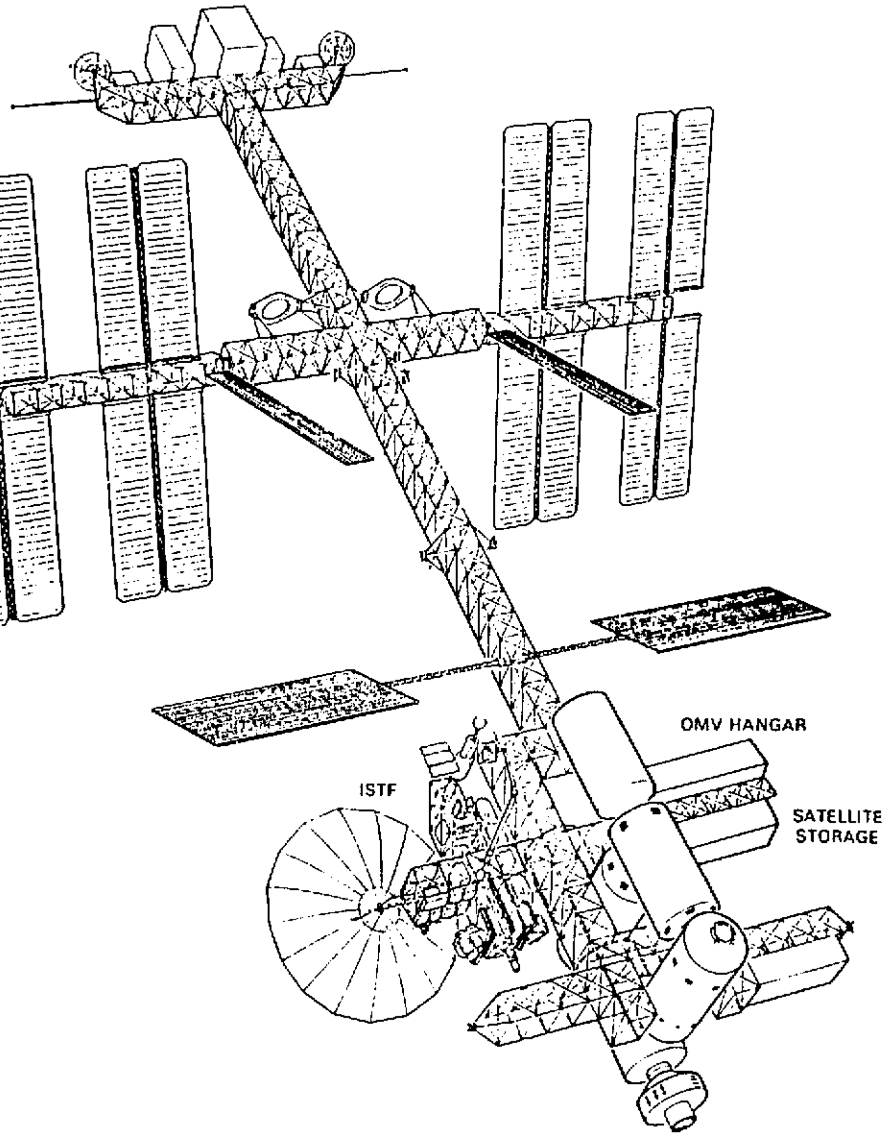


FIGURE 4: ISTF LOCATION ON SPACE STATION

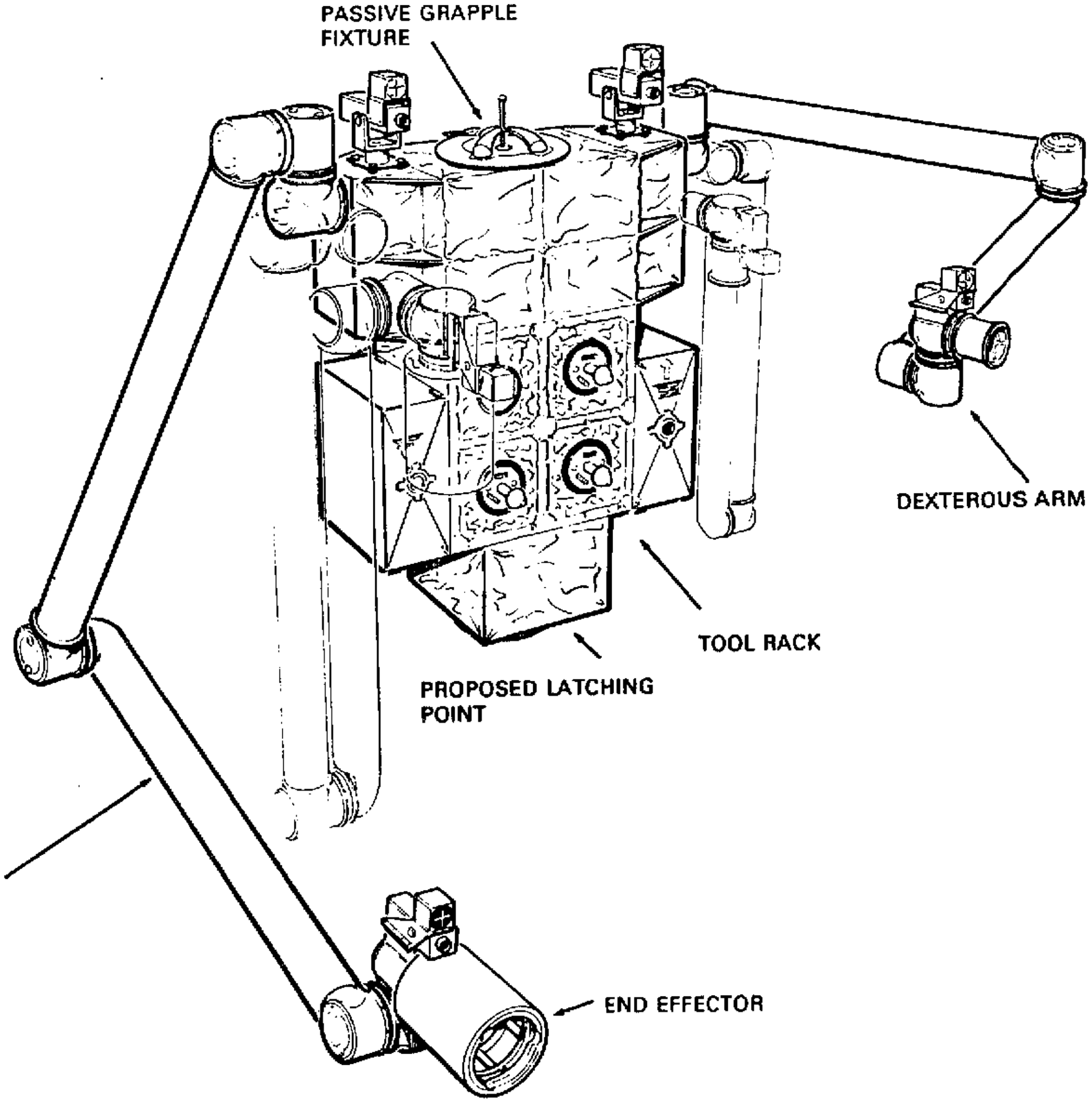


FIGURE 5: ROBOTIC SERVICER

Roger Crouch
Chief Scientist
Microgravity Sciences & Applications Program
NASA Headquarters

The U.S. Microgravity Science and Applications Program, is structurally located in the Office of Space Science and Applications, where Dr. Edelson is the head. We're a very small part and Dick Halpern is the Director of our program.

I want to give you an overall philosophical view of what our program is. It is a very successful program and I think it's almost an ideal way to run a research program, to go into microgravity and to bring the commercial people into the space program. I'm going to give you a lot of information, but primarily what I want you to understand is that what we're doing in the Microgravity and Science Applications Program, is establishing a data base. The purpose of this database is to define the parameters that are affected by the space environment and through that definition, tap into the creativity and the serendipitous synergism that exists between Government organizations, academia and industry that will allow them to utilize the space environment for learning new knowledge, that will advance processing either here on earth or in factories in space. Which in my opinion, are a long way away.

The way we run the program out of NASA is that we have basically four types of centers. We have:

1. In-house research located at various NASA centers.
2. University sponsored research where we do basic and applied research.
3. Industry sponsored research which are called technical exchange agreements, industrial guest investigators and JEAs.
4. We have approximately five centres of excellence, the basis of which is grant funding to various centres in the country to do fundamental research for conceptual development of various ideas for going into space. These include the MIT group that we have in materials science; an NBS group in metals and alloys and thermal physical characterization; the Institute of Theoretical Physics is looking at some fluid flow phenomena; the University of Arizona and the University City Science Centre in Philadelphia are biotechnology/ bioprocessing centers that we have funded.

The goals of our program are primarily to establish this data base to stimulate, excite, fund, whatever the procedure is to get people to think of experiments in the paradigm where we're talking about convective effects. Primarily, when we go to space we get gravitational effects. Primarily gravity affects fluid flows, so most of the work that we fund is based around fluid flow phenomena. There are other phenomena, very high vacuums and so forth and I'll get to that later. But the process is to establish a data base to do some good science, not to do serendipitous things.

What we're really looking for is good science that gives people a concept of what the processes are that go on in earth processing and how microgravity science can relate to those processes in a way that will give them insight into improving them. Through this, we want to create their interest in the low gravity environment.

The way we disseminate this information is that we try to publish papers. We encourage the people who are funded under our program to publish in the open literature. Over the last four or five years, there's been a tremendous increase in the amount of recognized science that's coming out of NASA's program in ground-based research, leading to and including microgravity science. Most of these articles are on ground-based research. A strong scientific ground-based program is very important and this is the evidence of that. We have not flown that many flights in the various areas that we fund, but we are doing significant ground-based work in my opinion.

Experiments don't come into our office in a mature state where they're ready to fly. There must be preliminary ground-based work done because it's very very expensive to fly a space experiment and it's very rare that we get to fly these things. Thus we must develop and optimize the experiments to the absolute maximum for the science that can come out of the microgravity environment through ground-based programs.

Basically the way our program runs is that new ideas come in from various sources: University Research; NASA R&T Base; other Government Research; and Industrial Research. These sources go through a Concept Feasibility (stage I) where we fund the determination of whether there is a fairly strong indication that microgravity is required to understand the phenomena that the people are interested in studying. Then we carry it into a Detailed Laboratory Investigation (stage II) to show that there are convective effects in the phenomena that are being studied. Then we go into Low Gravity Effects Confirmation (stage III). Those of you who are intimately involved with the program know that "zero"-g is a fallacy, it's also an erroneous fallacy if you start believing that everything stops when you get up there. You wind up believing that everything is Marangoni flow, which leads you to believe that if you don't have any free surfaces then you can do anything you want to out there and this is just not true. What happens is that there's sort of a feedback from the Key Space Experiments (stage IV) back into the effects of gravity, and this then feeds into the Commercialization Opportunities through which we indicate what the capabilities of space are. We indicate the phenomena that can be studied and understood better by getting into space, and this feeds back into creating new ideas and new concepts for people to develop different types of experiments that will lead to space experimentation.

Why microgravity? I don't intend to talk about that other than to say that if you reduce gravity, you reduce force convection, you reduce bouyancy driven convection, you reduce sedimentation, you reduce hydrostatic pressure.

These are the bonuses of microgravity:

1) An Ultrahigh Vacuum of approximately 10^{-14} Torr behind a wake-shield. This is wonderful if you want to do an MPE experiment. The problem is that NASA doesn't have a wake-shield yet so you're talking about four or five years before the concept.

2) It gives you an Infinite Pumping Speed -- imagine a huge umbrella that's acres in area, behind which 10^{-14} Torr and the pumping rate is absolutely infinite. It's a good concept, it just hasn't been brought into reality yet.

3) High Heat Rejection -- there's basically 4°K background radiaition.

4) Flux of Oxygen Atoms -- you can get a collimated beam of 5 ov O atoms. You can watch things disappear.

5) Unfiltered Sunlight -- a source of VUV, especially 121.6 nm which allows you to watch things brittle up and fall apart.

It's that kind of an environment.

Our program in microgravity science is primarily based on the keystone of fluid dynamics. The reason for this is that the strongest effect in going to space is a reduction in the gravity forces. Certainly there are other convective forces that come into play as you reduce the gravity force and bouyancy driven convection is retarded when you get to space.

We break our program down -- and it's an artificial breakdown because we don't want the outline to be 20 pages long -- into six disciplines, and I'll go through those in detail.

What these disciplines break down into are:

1) Fluid Dynamics and Transport Phenomena;
2) Metals and Alloys;
3) Electronic Materials;
4) Combustion Science.
5) Biotechnology;
6) Glasses and Ceramics;

These are generic types of disciplines that are affected by transport phenomena. I want to run through each of these discipliunes and just show you basically the types of experiments under each category that we're funding.

Fluid Dynamics (Figures 1,2) We're looking at critical point phenomena; surface behavior; chemical reactions; cloud physics; and relativity experiments -- relativity experiments can go into two or three different categories. The specific heat of helium at the lambda point is 2.8 degrees or whatever the transition from helium to helium-2 is, this is the

Cryogenic Equivalence Principle. There is some fundamental science in this, but there's also some basic convective mechanisms that go on when you have free surfaces such as the Marangoni flow and so forth. Other areas that we're funding under fluid dynamics and transport phenomena are thermo diffusion capillary flows; diffusion effects; electromagnetic flows and molten metals. Dr. Szekely is looking at how having an RF source as your heater, perturbs the convective flows that go on in the drop. We also do solidification modeling.

In each of our experiments, we try to cover three different areas. We try to determine a theoretical basis, we try to do an experimental verification, and we try to do a characterization and analysis. It's important that each thing have a sound theoretical basis for why that experiment needs to be run. Then you need an experimental verification of that, you need ways of checking the theory and you need analysis of the different types of experiment that can verify whether the theory is in fact correct.

Metals and alloys (Figures 3,4) We're looking at monotectics; eutectics; undercooling experiments by getting rid of convection. We seem to be able to reduce significantly, heterogeneous nucleation and look at more homogeneous effects. We look at solidification fundamentals -- the iron-carbon alloys; thermo-physical properties -- how can you do thermal modelling if you don't know what the thermal diffusivity, the specific heat and the various thermal physical properties of the material are. We're looking at vapor deposition --whisker growth; and what is the microstructure in a metals and alloys solidification front and how do you model that if convection is present.

Electronic materials. (Figure 5) In electronic materials, we primarily break that down into categories of various types of growth techniques: vapor growth; melt growth; solution growth; and float zone.

Combustion science. (Figure 6) Primarily combustion science developed out of how to understand what fluids do in rocket tanks. Then it got into a question of safety and now what we're looking at are the various ways that flame propagates, various ways that ignition takes place and what happens when we have burning in different types of configurations.

Biotechnolgy. (Figure 7) Almost everybody here, at one point or another has heard of CFES, which is the continuous flow electrophoretic separation process which McDonnell Douglas has put a lot of their money into. We're also looking at different types of separation techniques and biological processing. One of the programs that I'm very excited about is the protein crystal growth experiment and a bioreactor where we're looking at cell development and cell processing and space.

Glasses and ceramics. (Figure 8) We're looking at new glass compositions -- the same kinds of things that the scientists in Canada have seen significance in; fining -- how do we get rid of bubbles when we go to a low gravity experiment, how do we form fibres and, what kind of surface tension effects come into effect if you start to try to extrude very long fibres; spherical shells are based out of the Jet Propulsion Lab in California, and the basis for them is the containment for fusion targets; thermophysical properties -- we fund research in the areas of characterization. If we're talking about 2000°C, it's not easy to measure thermophysical properties of materials in that range. So how can you model furnace experiments when you're up in that kind of temperature range if you don't know the thermophysical properties?

Tools of the trade. The tools of this trade are basically:

1) Ground-Based Research
2) Drop Towers
3) KC-135
4) Shuttle Experiments.

I'll go through this in much more detail here

Drop towers. We have a KC-135 at NASA, a Lear jet, and an F-104, all of which can get up to 30 seconds of low gravity, and mid-deck lockers and so forth. I'll go through this in detail as I continue. In the drop tube facility, we have a 100-meter drop tube that gives us approximately 4.5 seconds. This is great if you're doing a quenching experiment, but when doing a directional solidification experiment where the growth rates are on the order of millimeters per day, it's just not very feasible. So this is good for doing certain types of the undercooling experiments, it's good for doing some feasibilty studies and some metals and alloys or some glasses. But it is not a very powerful process for long range development.

The KC-135. This airplane can fly parabolic orbits that give you on the order of 10^{-2} g for up to 20-30 seconds. If you go for 40 seconds, you tear the wings off and you only get one parabola. So we go for 20-30 seconds, somewhere in that range. But here again, we've basically extended the capability of the drop tower by almost a factor of ten. We also have much more power capabilities and we have the capability of doing some feasibility studies for what can be done in the shuttle environment.

Space Shuttle Experiments. We can do everything on this. We have Mid-Deck Experiments, we've got Spacelab, we've got Getaway Specials, Pallets, and the AFT flight deck. The experiments are all down in the bottom or back in the back. A Mid-Deck Experiment -- in the mid-deck there are some lockers. These were primarily put in for the crew to store their facilities in, whatever they decided to take with them. But what turned out to be much more practical was to limit the number of these that were available, for experiments. In these experiments you can develop hardware that can be either man-tended or automatic as long as it's low power because there's a limit in the mid-deck experiments as to how much power you can have. You have a limit on what the outside temperature of the facility can be. You also have a problem that as we go up in crew size, and as we try to fly scientists as opposed to mission specialists, the locker spaces really go down. Thus, in the lockers, or in the galley, there's a capability of running certain experiments and that's a wonderful facility for doing microgravity experiments. It's also very crowded. We funded a series of experiments on a monodispersed latex reactor system and what came out of that was the capability of producing uniformity in space of the spheres compared to what you can produce on earth. We now have a commercial product, the first commercial product from space that is really the standard for 30 micron spheres and it's incredible to make. I was amazed at the number of corporations that use these types of things for calibration. We have the capability of going up to 100 micron spheres which we cannot do here on the ground. The standard deviation goes down by about a factor of four between what we can get out of space and what can be done here on the ground as you go up to the larger diameters .

Then we have Cargo Bay Experiments. We have a Materials Experiment Assembly (MEA) facility, we also have what's called a Materials Science Lab. The Material Science Lab is basically a carrier. The Hitchhiker, as I understand it, is basically a carrier and that's what this is except it has certain amounts of power capabilities, certain amounts of cooling capability and it has recorders built in. This is negotiable, but we can get megabits out of this if we wanted.

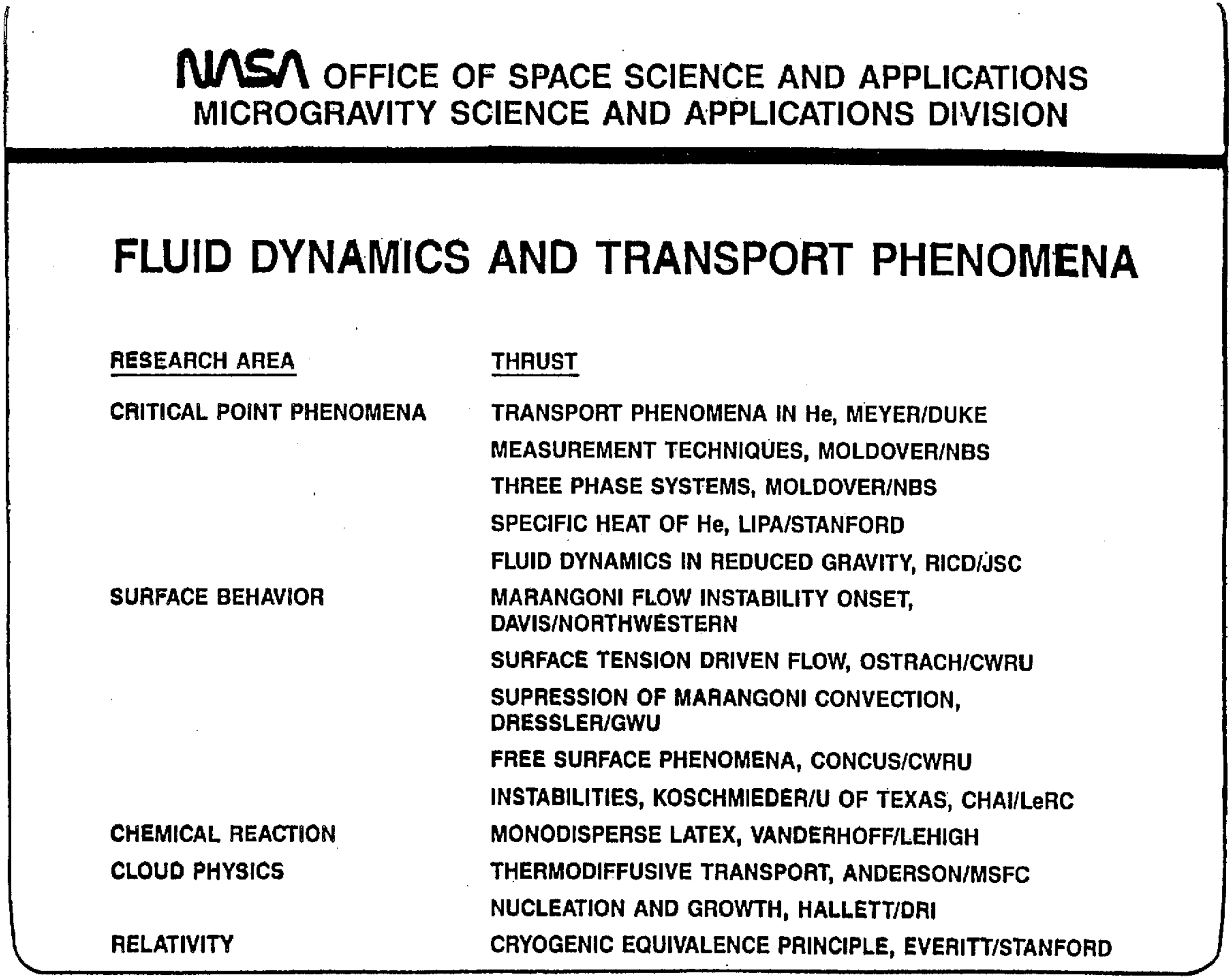
We do have cargo bay carriers on which you can mount a number of experiments, GAS cans. It's just a carrier that will let you take different facilities up into space.

We have certain hardware that we have built or that we are building as PI's, Principle Investigators, in the U.S. community. If you want involvment in our program using this kind of hardware that we've already developed, find out who these people are. Call them up and get to be part of the program.

Apparatus for microgravity science and applications experiments available at present are:

Available

- General purpose furnaces, isothermal and gradient
- Single-axis acoustic levitator furnace
- Monodisperse latex reactor
- Directional solidification furnaces
- Advanced containerless experiments system (JPL)
- Fluids experiment system/vapor crystal growth system
- Continuous flow electrophoresis system



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MICROGRAVITY SCIENCE AND APPLICATIONS DIVISION

FLUID DYNAMICS AND TRANSPORT PHENOMENA

RESEARCH AREA	THRUST
CRITICAL POINT PHENOMENA	TRANSPORT PHENOMENA IN He, MEYER/DUKE
	MEASUREMENT TECHNIQUES, MOLDOVER/NBS
	THREE PHASE SYSTEMS, MOLDOVER/NBS
	SPECIFIC HEAT OF He, LIPA/STANFORD
	FLUID DYNAMICS IN REDUCED GRAVITY, RICD/JSC
SURFACE BEHAVIOR	MARANGONI FLOW INSTABILITY ONSET, DAVIS/NORTHWESTERN
	SURFACE TENSION DRIVEN FLOW, OSTRACH/CWRU
	SUPRESSION OF MARANGONI CONVECTION, DRESSLER/GWU
	FREE SURFACE PHENOMENA, CONCUS/CWRU
	INSTABILITIES, KOSCHMIEDER/U OF TEXAS, CHAI/LeRC
CHEMICAL REACTION	MONODISPERSE LATEX, VANDERHOFF/LEHIGH
CLOUD PHYSICS	THERMODIFFUSIVE TRANSPORT, ANDERSON/MSFC
	NUCLEATION AND GROWTH, HALLETT/DRI
RELATIVITY	CRYOGENIC EQUIVALENCE PRINCIPLE, EVERITT/STANFORD

Figure 1

METALS AND ALLOYS

RESEARCH AREA	THRUST
MONOTECTICS	InAl & TeTl, GELLES/GELLES ASSOCIATES
	PHASE SEPARATION, FRAZIER/MSFC
EUTECTICS	MnBi & CoSm, LARSON/GRUMMAN
	MAGNETIC FIELD EFFECT, PIRICH/GRUMMAN
UNDERCOOLING	NI BASE ALLOYS, FLEMINGS/MIT
	NbGe, BAYUZICK/VANDERBILT UNIVERSITY
	QUENCH RATES, COLLINGS/BATTELLE
	NI, PEREPEZKO/UNIVERSITY OF WISCONSIN
	CONTAINERLESS TECHNIQUES, TRINH/JPL
	NI AND Fe ALUMINIDES, KOCH/NC STATE
	METALLIC GLASS, LEE/JPL

Figure 3

METALS AND ALLOYS (CONT'D)

RESEARCH AREA	THRUST
SOLIDIFICATION FUNDAMENTALS	BINARY ALLOY SOLIDIFICATION, LAXMANAN/CWRU/LeRC
	DENDRITE GROWTH, GLICKSMAN/RPI
	SEGREGATION, HELLAWELL/MTU
	IRON-CARBON ALLOYS, STEFANESCU/UNIVERSITY OF ALABAMA
THERMOPHYSICAL PROPERTIES	THEORETICAL MODELING, STROUD/OHIO STATE
	SPECIFIC HEATS, MARGRAVE/RICE
	CALORIMETRY TECHNIQUES, BONNELL/NBS
	PULSE CALORIMETRY, CEZAIRLIYAN/NBS
	CRITICAL POINT WETTING, KAUKLER/UAH
	HIGH TEMPERATURE MATERIALS, MARGRAVE/RICE
VAPOR DEPOSITION	WHISKER GROWTH, HOBBS/GWU
CONVECTION	MICROSTRUCTURE, WILCOX/CLARKSON

Figure 4

ELECTRONIC MATERIALS

RESEARCH AREA	THRUST
VAPOR GROWTH	FLOW MODELING, ROSENBERGER/UNIVERSITY OF UTAH
	GeSe, HgCdTe, WEIDEMEIER/RPI
	HgI2, SCHNEPPLE/EG&G
MELT GROWTH	FLOW MODELING, BROWN/MIT
	GaAs, GATOS/MIT
	HgCdTe, LEHOCZKY/MSFC
	PbSnTe, CROUCH/LARC
	INTERFACE CONTROL, WITT/MIT
	GaAl, KAs, BACHMANN/NC STATE
SOLUTION GROWTH	TGS, LAL/ALABAMA A&M
	ORGANIC CONDUCTORS, HEEGER/UCSB
FLOAT ZONE	TECHNIQUES AND ANALYSIS, KERN/WESTEC
	PROPERTIES OF SI, HARDY/NBS
	OXIDE SKIN FORMATION, VERHOEVEN/IOWA STATE
	SOLIDIFICATION OF Ge-SI, JEMIAN/AUBURN

Figure 5

COMBUSTION SCIENCE

THRUST	
LEAN LIMIT FLAMES	STREHLOW/UNIVERSITY OF ILLINOIS
SMOLDERING	PAGNI/UC-BERKELEY
DROPLET BURNING	WILLIAMS/PRINCETON
PARTICLE CLOUD	BERLAD/UCSD
FLAME SPREADING	ALTENKIRCH/UNIVERSITY OF KENTUCY
GAS JET DIFFUSION	HARSHA/SAI
POOL BURNING	SIRIGNANO/UCI
PREMIXED TURBULENCE FLAMES	LIBBY/UCSD

Figure 6

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BIOTECHNOLOGY

RESEARCH AREA	THRUST
NEW TECHNIQUE DEVELOPMENT	ELECTROPHORESIS MODEL, SAVILLE/PRINCETON
	ISOELECTRIC FOCUSING, BIER/UNIVERSITY OF ARIZONA
	INSTRUMENTATION FOR PHASE PARTITIONING, HARRIS/UAH
	CELL PARTITIONING, BROOKS/OREGON
	POLYMERIC MAGNETIC MICROSPHERES, REMBAUM/JPL
EVALUATION OF CFES	ELECTROPHORESIS, SNYDER/MSFC
	GROWTH HORMONE, HYMER/PENN STATE
	PROTEINS, SNYDER/MSFC
	CHARACTERISTICS OF KIDNEY CELL GROWTH, TODD/PENN STATE
	CONCENTRATION LIMITS, CAPRIOLI/U. TEXAS MEDICAL CENTER
	CELL CANDIDATES, JOHNSON/U. TEXAS CANCER CENTER
	BIOMEDICAL PRODUCTS, ATASSI/BAYLOR MEDICAL COLLEGE
	ALL CULTURE FLUID MECHANICS, NEREM/UNIVERSITY OF HOUSTON
	RADIOMMUNE ASSAYS, KNUTSON/BAYLOR MEDICAL COLLEGE
PROTEIN CRYSTAL GROWTH	PROTEIN CRYSTAL GROWTH, BUGG/UAB
	PROTEIN CRYSTAL GROWTH, FEIGELSON/STANFORD
BIOREACTOR	BIOREACTOR DEVELOPMENT, MORRISON/JSC

Figure 7

GLASSES AND CERAMICS

RESEARCH AREA	THRUST
NEW GLASS COMPOSITIONS	HIGH TEMPERATURE MELTS, ETHERIDGE/MSFC
	FLOURIDE GLASSES, DOREMUS/RPI
	OXIDE GLASSES, DAY/UNIVERSITY OF MISSOURI
	SOL-GEL GLASSES, MUKHERJEE/JPL
	NEDOX CRYSTALLIZATION, WILLIAMS/JSC
FINING	BUBBLE REMOVAL, SUBRAMANIAN/CLARKSON
	MODELING, WEINBERG/JPL
	SURFACE TENSION EFFECTS, UHLMANN/MIT
SPHERICAL SHELL	SPHERICAL SHELL TECHNOLOGY, WANG/JPL
	PRECURSOR MATERIALS, DOWNS/KMS
FORMATION	NUCLEATION AND CRYSTALLIZATION, WEINBERG/JPL
	SOLID-STATE COMBUSTION SYNTHESIS, HURST/DOE/LERC
	METALLIC GLASSES AND AMORPHOUS SI, SPAEPEN/HARVARD
THERMOPHYSICAL PROPERTIES	ATOMIC FLUORESCENCE, NORDINE/MRI

Figure 8

INTERNATIONAL MICROGRAVITY LABORATORY (IML)

BASIC IML GUIDELINES:

- IML IS A PROGRAMME CONSISTING OF 3 SPACELAB FLIGHTS.
- IML CONSISTS OF MICROGRAVITY EXPERIMENTAL FACILITIES (RACKS, DOUBLE-RACKS) DEVELOPED BY U.S. AND NON-U.S. ORGANIZATIONS/AGENCIES.
- NASA WILL COVER, FREE OF CHARGE, THE IML LAUNCH COSTS AND THE LEVEL II/III INTEGRATION COSTS OF ALL U.S. FACILITIES AND OF THOSE NON-U.S. FACILITIES IN WHICH NASA IS INTERESTED FOR THE EXECUTION OF U.S. EXPERIMENTS
- THE PAYLOAD COMPOSITION OF THE 3 IML MISSIONS MIGHT CHANGE. EXCHANGE OF RACKS IS RECOMMENDED.
- NON-U.S. FACILITIES WILL BE USED TO ABOUT 50% FOR THE EXECUTION OF U.S. EXPERIMENTS. THE OTHER 50% USAGE IS RESERVED FOR THE OWNER OF THE FACILITY, WHO MAKES HIS OWN EXPERIMENT SELECTION.
- U.S. FACILITIES CAN BE USED ALSO BY NON-U.S. EXPERIMENTERS VIA THE WORLD-WIDE AO OF THE FUNDING NASA PROGRAMME OFFICE.

Figure 9

THE ROLES OF THE
MISSION/PAYLOAD SPECIALIST

by

A. W. England
Lyndon B. Johnson Space Center

Dr. Tony England
NASA Astronaut - Spacelab 2 Flight

Spacelab-2 was my first flight and I've had several opportunities this fall to talk about it to different groups. A few weeks ago I talked to a group, the title of whose session was "Another Routine Year in Space". Our flight if you remember, was the one that got to three seconds before launch and had a main engine shut down. Then when we finally did get off the ground two weeks later, about half way up to orbit we had one engine shut down. So, while getting to space for the first time may be routine for a lot of people outside, you'll find that it is not at all routine for the participant.

It was suggested that I talk about the working environment on the shuttle and Spacelab, which will probably be somewhat better than Space Station and an evolution of what we have in the shuttle. I encourage questions and what I want to do is stimulate discussion to find what you really want to hear about. I'm not going to talk about Spacelab-2 because it was primarily astronomy and plasma physics and in no way related to material processing.

First of all, when you're going to fly an experiment in space you have to decide who is going to carry out the experiment. That is if it's a manned experiment. And there are two options as most of you are aware. One is use the mission specialist, these are the career people like myself down at JSC and the other is to use a payload specialist. I've listed pros and cons of using both in figure 1. Actually I favour using the payload specialist and I'll explain why.

The mission specialist is most likely to have flight experience either first hand or second hand, because we all reside in the same office and even if you haven't flown yourself, you've spent years working with people who are flying and you have a good idea of what you can and can't do in space. He knows the orbiter and the space operations well and it's extremely useful to work with the mission specialist in designing your flight plan. Where you want quiet periods, whether you want to restrict water dumps, what g levels you want and whether you have to restrict crew motion.

Crew motion is a major source of accelerations on the orbiter. Our instrument pointing system pointed at the sun to about an arc second resolution, there are 1800 arc seconds across the sun, so you get an idea of what kind of accuracy we had. The resolution of the telescopes was more like 1/100 arc second, so we could see small scale jitter on the sun just due to the precision of the instrument pointing system. It was sensitive enough that we could also do experiments with pushing off the floor or typing on the computer keyboard and you could see the telescope jitter just from typing on the keyboard. The small jets onboard put out 25lbs of thrust and that works out at about 10^{-4} g. When you move on the orbiter, it's possible to give an impulse of about 25lbs for a very short amount of time and you'll have the same kind of acceleration. If you want lower acceleration levels than that you have to specify it and then the crew has to be provided with time in fact to float free and not do any work.

Generally the mission specialist also knows the NASA system well, and if you can enlist their support you can find out how things are done that sometimes are very difficult to do otherwise. Also he can perform Extra Vehicular Activity, EVA's if they're needed. We had so many contingency EVA's for the paylod that we were flying that we wanted to schedule an EVA and cancel it if it wasn't needed. But they wouldn't go for that.

Disadvantages of the mission specialists is you have a shared attention. It isn't his primary job to work on one payload, and it can't be. He has to operate the orbiter systems and he usually has several payloads that he's responsible for. It's like any other structure, his boss is someplace else rather than the Principle Investigator on the payload. So you don't get 100% attention and he's usually not a specialist in the payloads technology. While we have material scientist types, your chance of getting one probably aren't very high. We seem to insist that our mission specialists be generalists. While I'm a geophysist, I flew on an astronomy mission and that's typical of flight assignments.

The mission specialists are also not really available more than about one year before the flight. While this was untrue in early Spacelabs because there was the stretch-out on the shuttle develpment, it will be increasingly true in these later missions. The policy seems to be that we will assign the mission specialists about a year ahead and assign the pilots more like 6 months to 9 months before flight. He will then disappear about two months after the mission so if you want him available for post flight analysis and redesign of the experiment, he probably won't be. We do provide some mission specialist support for future payloads. My technical assignment between mission assignments, is to head the Mission Development Group. What we do is look at new payloads coming along at the Payload Integration Planning stage, the PIP stage, and go out and work with the experimenters where necessary. We try to give them some idea of what can and what can't be done so that they don't end up near a fligh with something that's very difficult to do.

For the payload specialist , the advantage is that he is responsible to the payload team. He may be a specialist in the appropriate technology and he's available wheaever required by the payload -- before, during and after the mission. And I think those are very important things, particularly that last one. There is so much that goes on in developing a payload and the flight plan for the payload, that unless you've been through it once you can't imagine the demands on time. To have someone who is dedicated to operating the payload, with the investment that he's going to have to do it himself is really very important.

The disadvatage of the payload specialist is he often has little knowledge of the orbiter or how NASA operates. He often has little first or second-hand flight experience and it's difficult for him to operate the orbiter systems. He's usually not allowed to. And payload specialists can't do an EVA.

I've been involved in my own science. I was outside of NASA for seven years, from 1972-1979, where I was doing research in remote sensing geophysics with the U.S. Geological Survery. So I have an experimenter's view of using the orbiter. One of my activities on the side, over the last few years has been to get payload specialists onboard for particular experiments. For instance, I understand we're going to have one for the shuttle Imaging Radar. And I think those are very important things. I talked to the development engineer at JPL for that radar and asked him what kind of crew interfaces he was going to have and he said well that depends on who I've got operating it. If it's one of the NASA mission specialist types, we'll put a very limited interface and try to control it from the ground. If there's somebody onboard that I could trust, then I would put an exotic interface onboard and we'd have a lot more flexibility. I think in a development system the latter is what you really want. So it is important if you can do it, to have the payload specialist onboard.

I want to say another word about chosing a payload specialist. NASA doesn't advertise it, and I don't think the success of various payload specialists and what they try to do is written about anywhere. Talking purely from my own observations and I wouldn't write it down, there's been mixed success. Some payload specialists have been really good. The two payload specialists on Spacelab-2 were excellent. They were career practicing solar astronomers. One was from the Naval Research Lab and the other was from Lockheed Research and they were particularly good team players. You don't fly the scientists onboard for that serendipidous discovery, you fly them to be part of a team, where most of the members are on the ground. So you want somebody who works with a team and these folks did that very well. Not only with the team on the ground but with the team onboard. Because they were so good to work with, they got a lot more out of the orbiter crew than other sets of payload specialists would have. All of us went out of our way, we mission specialists and even the pilots who sometimes aren't that interested in payloads did all they possibly could to make Spacelab-2 a success. It was generally said to have been a success, and I think that those payload specialists and their sense of teamwork were a big reason for that. I think that one criteria that you can apply when you chose a payload specialist is to ask yourself, is he someone that you think you would be comfortable going camping with for a long time. If he's someone who's co-operative and you can work with in that sense, then he would probably be a pretty good payload specialist. If he's really eccentric and very difficult to work with, he'll be very difficult to work with onboard. There are examples of that and some of them haven't worked very well.

Does that mean you only get to talk to a mission specialist up until two months after the mission?

Generally that's true. We have a two month post mission period where we still belong to the payload. And our travel can be just a trivial example, but we can write off our travel to that payload. But after that time, I can't get travel approval to get to a Spacelab-2 function. I mean that's a trivial example, but that just shows the thinking there is. We've done our crew reports, we've given our debriefing, now onto something else.

If I was to design an experiment to go into space, I couldn't expect someone to watch it for hours, is that right?

I think that depends on whether you've provide the someone. In the electrophoresis experiment, the payload specialist who went with the experiment did nothing for the whole period he was up there but operate the piece of gear as many hours as he could. If you use a mission specialist, unless it's almost the only payload onboard, you couldn't count on that kind of attention. I think that it really depends on what you want done. If you want to design it to be unattended, a lot of experiments are designed that way. One of the disadvantages of designing it to be unattended is you still usually put some pretty great restraints on the orbiter and what kind of accelerations are allowed. If you have a payload specialist onboard, you have the advantage that he's involved in developing the flight plan and is aware of what is planned and can very early effect the constraints in the flight plan. What I'm saying is if you don't have someone involved in the flight planning, and you cannot be legal enough to write everything you want down, something could appear on the flight plan that you're very unhappy with. Because of competing needs for the Resource Orbiter Attitude for example.

What are the differences between how a mission specialist and a payload specialist are chosen?

Mission specialists are chosen by essentially a very small group of people. Almost a group of one down at the Johnston Space Center. And the requirements are really for generalists. In fact, if you look at the groups that have beens selected in the last few years, there are fewer and fewer people who have a history of very many years of research. On the last few groups, most of them have been engineering types with Masters Degree level backgrounds. They are extremely dedicated people and they're very bright people generally. They will do a good job for you, but they're not supposed to be and not encouraged to be specialists in any technology.

The payload specialist on the other hand, is chosen by the Investigators Working Group, which is composed of the Principle Investigators for all the experiments that are flying on the mission. They become the employers of the payload specialists and therefore have a lot more control of what the payload specialists do. The payload specialist reports to the investigators working group. In a little while I'll get into the interface between the payload specialists and the mission specialists as the mission approaches.

How much it would cost for someone to train a mission specialist?

I don't think that NASA charges for that. That's considered normal services for the payloads so it just comes with the cost of flying the payload. There is a cost associated with the payload specialist and I don't know what it is. It would include his salary plus overhead, in theory it comes to about $200,000.

Now let's go onto Figure 2, The Working Environment. There was a question about the voice communication with the Payload Operations Control Center, the "POCC" we call it. That's where your Principle Investigators will be. And increasingly, that POCC will be located at the mission center rather then at JSC. We have one at JSC but starting with D1, the German Spacelab that launches on the 30th of October, we're going to have a POCC in that case over in Germany and then with Astro the POCC will be at Marshal. So more and more this POCC where the investigators are, will be at the Mission Development Center. When we get into the 2 TDRS era, that's what I'm talking about here because presumably nothing that we will discuss tonight would fly before we have 2 TDRS up there, you're talking about 85% voice coverage. Our experience has been that unless you have a large orbiter involvment, for example on Spacelab-2 we spent two days deploying a small satellite and flying around it, and going back and picking it up. That's a heavy orbiter involvement and the investigators can't have 100% access to the available communications time. But for the rest of the experiment, we were twice in orbit doing an attitude manoeuver, and otherwise we were doing either solar observing on the sun side or X-ray observing on the dark side. For that period, the communication entirely belongs to the POCC and you can have direct payload crew to PI in the backroom if that's the way your POCC people want to do it.

We had periods where the payload specialist was simply talking one on one with the various experimenters on how to operate his instrument. And that was the norm for the last few days of the mission.

In regard to the payload-to-ground data rate, if you have less than two megabits per second and your data, then almost continuous payload TV is available. So not only does the ground have voice communication with the payload crew, but you may be able to see what's going on onboard. We find that so useful that for Spacelab-2 reflight, several of the PIs are reformating their data to reduce the data rate needed so that they can have continous TV. We had TV through the telescope so they could see the targets on the sun.

We will have uplink. We have now uplink teleprinter and increasingly we're going to a real time flightplan that's uplinked every 12 hours. We had typically, a length of teleprinter paper that would be eight or nine feet come up every twelve hours. And then we flew off that rather than depending on the elaborate flight plan that we had developed over months before we ever got to orbit. With that engine problem we had, we got into a lower orbit and it forced them to start replanning. It turned out to be a blessing in many ways because as we learned things, they modified the flight plan and we ended up with a better flightplan than we had planned. I think that in the future you'll see less of the preplanned flight plan and more of 'I'll send up in a few hours what you're going to do for the next twelve'.

We used up 400 feet of teleprinter paper on our eight day mission. In addition to the teleprinter in that era, we'll also have graphics capability where you can send graphics up. Just mentioning a few other things that are typically available to the crew onboard. I'm saying these thing because if you want something in addition to that, you have to provide it as part of the experiment. We have two colour TV cameras in the living area. We had a VCR in the living area and we for example, looked through two telescopes of the four on the instrument pointing system at the sun and we recorded all the data that we were getting through those telescopes on a VCR so even when we didn't have air to ground, they could recover it post mission. There are two 70mm Hasselblad cameras for outside photography; two 35mm Nikons with flash and a 16mm Arriflex movie camera with a flood for interior photography. Those are typical tools that you always have. We have a good mechanics tool set and voltometer onboard, but we don't have oscilloscopes and that kind of thing and we don't have wirewrap kinds of tools. So if you want those things done, you have to provide them. You have utility outlets all over the walls just like at home except that ours are 110 Volts, 400Hz and 28 Volts. Stowage in the mid-deck is extremely limited as pointed out earlier. Its become such a popular area for small carry on experiments that it's just not available for general storage. So everyone fights for mid-deck locker space. The air is clean. We didn't see any of the stuff floating around that some of the earlier crews had talked about. The air is dry at about 45% humidity and it's comfortably cool. I started out wearing shorts thinking it was going to be warm up there because all of the thermal studies said it was going to be around 90°F and found that it was too chilly. It was just a very comfortable working environment.

Personal hygiene systems are adequate and I'm saying this for the people that you're going to chose to fly for you. But everything takes about 25-50% longer than a equivalent ground system. Any questions on this one?

Are the reflexes of the astronauts actually slower?

Well you have to be more careful. The consequences of an error are more drastic.

What's the cost for a mid-deck locker like?

Dr. Crouch's answer: "Right now they're used exclusively for internal NASA experiments and for commercial experiments where NASA has a special arrangement that we can talk about later. There is no charge that has been made to date for mid-deck lockers. The problem with the mid-deck locker space is that it is a question of space and the number of astronauts. Each astronaut requires a minimum of three lockers. Everytime you put a Senator onboard, you lose two lockers."
And the backlog is about 50 mid-deck experiments right now.

There was a newspaper report a few months ago about the degeneration of muscle tissue. Is that true and how does it effect any longterm Spacelab experiments?

Spacelab isn't up there long enough to really have much of a human factor problem. It showed up in the rats because they lose their muscle mass much faster than a human does. For a very long duration facility, loss of muscle mass and bone mass does in fact become a significant problem and you have to set up at least an exercise regiment to try to curtail that. Turns out that bones respond to stress much the same way muscles do, just slower. If you don't stress them, you will lose bone mass. We have a treadmill system onboard as an experiment really, rather than something that we need for an eight day mission. It doesn't seem to be a problem for three months. If people are talking about six months or a year, it might get very serious. For the plan on the Space Station, it's thought to be managable.

<u>Crew performance</u> (Figure 3). One of the unfortunate overheads of the shuttle/Spacelab kind of mission is the Space Adaptation Sickness that about half your people are going to experience enough to be really noticible the first two days. Almost everyone experiences something, some of it just isn't much of a problem. But for about half your people, they're going to feel less than good for the first few days. On our mission, no one was feeling poorly enough that they couldn't do the job that they had intended during that time. Still it's best not to plan activities that require a lot of personal initiative for the first couple of days. The second thing is that anything you do in zero-g, will take a little bit longer because your body is less easily controlled. You find that if you start trying to move around fast you go bouncing into things and there are enough surfaces and switches

and whatall up there that you don't want to disturb, that you tend to move very deliberatly. It takes longer to do everything that you intend to do and everything that you grab or let go of has to be restrained in some way, you have to fasten it to something even if it's just velcro. So that takes longer. Because there are so many competing activities onboard, you find that housekeeping is important and so you end up breaking things out of storage and then putting them back into storage when you're through. So the overhead to doing anything is just greater. It's reasonable if you can do it in one-g, to add about 10-25% to the time to understand how long it will take you to do the same thing in zero-g.

However, the one advantage you have up there is that moving and positiong large or heavy objects is much easier. For example our chairs that we fly up with weigh 90lbs and in the simulator when we were taking them down and moving them into the mid-deck it was a major operation requiring cooperation between a couple of crewmen to move them over and put them down the access between the flightdeck and the mid-deck. Up there it was a simple thing, you just point it in the general direction and start it moving and someone would catch it over at the other end and start it moving in a different direction. Moving those things around was very easy.

The PS's onboard can expect help from the orbiter crew when it's needed. Generally the orbiter crew is available and are quite anxious to help. Housekeeping has to be considered a shared activity. The orbiter crew doesn't picture themselves as running an inn and there have been payload specialists who have thought that they didn't have to do their share of onboard work and that makes for some hard feelings sometimes.

Generally the amount of time that you can expect in a day on your project, depends a little on whether you're trying to work the whole flight period or wherther it's a one shot thing. If you're trying to work the whole eight days, I wouldn't count on very much more than 12 hrs a day. I found that we were working on the science part about 13hrs a day and by the eighth day, we were really tired. We had just about shot everything that we had and we couldn't have gone very much longer. So something like 12 or 13 hrs a day for an eight day mission is about all you can expect. Because there is a large overhead, they're living up there. If you work 13hrs a day, you're already at a maximum of 6 1/2 to 7hrs of sleep a night. Some groups are beginning to look at 8hr work days over a long period. I don't know which is best. Up in the Spacelab environment for a couple of weeks, I would prefer the 12hrs because there's nothing else to do. It's not as if you have a recreation you could go to or would want to. After preparing for this thing for all those years there's nothing you want more than to do something successful with your payload. So, the 12hrs worked very well for us, and I think that when you're talking up about a period of months or maybe even longer, if you can let up just a little bit, that kind of 12hrs is the way to go and I would plan on it. My experience in Antarctica for example, where we were in the field and travelling by motor tobaggan and living in tents which is a very physical environment, was that you paced youself so that at the end of the field period, you had shot everything you had. You were really worn out. And we were working about 12hr days in that situation.

STS Related Training for the payload specialist (Figure 4). The PS's will visit Houston something like three times for two day periods in the six to three month prelaunch period. This is for specific training that he's required to have. For the last three months, they actually based themselves in Houston, this isn't because they're working down there full time, they're only working there about 25% of the time. But the training that they get is irregular and when they're at a distance they're never available when the trainer is. So it turns out to work best to have them in Houston and travel to whatever else they're doing during that period. And then the last week or so, they're occupied by the STS about 50% of the time but they're required to stay there, they can't go anyplace else. They can worry about their payload the other 50% of the time, but they have to do it over the telephone.

transcribed by Pippa Wysong

CREW OPTION	ADVANTAGES	DISADVANTAGES
Mission Specialist	● Possible Flight Experience.	● Shared attention.
	● Knows Orbiter and Space Operations well.	● Usually not a specialist in the Payload's technology.
	● Knows NASA System well.	● Not available very much before launch - 1 yr or after landing + 2 mon.
	● Can perform EVA if needed.	
Payload Specialist	● Responsible to Payload Team.	● Little knowledge of Orbiter operations of NASA.
	● May be specialist in appropriate technology.	● Little first or second hand experience with spaceflight.
	● Available whenever required by payload before, during and after the mission.	● Very little access to Orbiter systems, and cannot perform EVA.

Figure 1

WORKING ENVIRONMENT

- If low Orbiter activity, then almost continuous direct payload voice communications (~85%).
- If payload-to-ground data rate <2Mbs and if no extreme Orbiter attitude requirements, then almost continuous payload TV available.(~85%).
- Uplink teleprinter and graphics available.
- STS crew cameras - 2 color TV cameras and VCR, 2 70mm Hasselblad cameras for outside photography, 2 35mm Nikon and flash and 16mm Arriflex movie and flood for interior photography.
- Good mechanics tool set and VOM available, but few other tools are normally flown.
- Utility power (110V, 400 Hz; 28V DC) available.
- Stowage on middeck is limited to a few lockers.
- Air is clean, dry (~45%) and comfortably cool (mid 70's).
- Personal hygiene systems are adequate, but take 25 to 50% longer to use than equivalent ground systems.

Figure 2

CREW PERFORMANCE

- 50% chance that crew's performance will be degraded somewhat during first 2 days.
- Equivalent activities in 1-g will nominally take 10 to 25% longer in 0-g because motions must be more controlled, all items must be restrained, and there is always a lot of stowing and unstowing.
- Positioning heavy or large objects is easier.
- PS's can expect help from the Orbiter crew when it is needed.
- Housekeeping is a shared activity among all Payload and Orbiter crew.
- Allow 1½ hr between wake-up and beginning work, and 2½ hrs between ending work and sleep (i.e., expect a 12 hr. work day).

Figure 3

STS RELATED TRAINING

- PS's will visit Houston for 3 2-day periods between 6 and 3 months before launch.

- PS's should base themselves in Houston for the 3 months before launch.

- PS's will be occupied at JSC 25% of their time for the last 3 months, but the training schedule is unpredictable.

- PS's will be occupied at JSC and KSC 50% of their time the week before launch, but they must remain at the NASA centers.

Figure 4

COMMERCIALIZATION OF SPACE ACTIVITIES

BY

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INTRODUCTION:

Prior to what we know as the dawn of civilization, mankind had invented or discovered a considerable treasury of technical instruments - the axe, the flint scraper, spear, bow and arrow, oil lamp, but they all were developed by small groups for use by individuals. Mankind had also been an explorer but again in small groups and they did not go very far.

When civilized man organized himself into governmental structures, he did so to create and explore on a grander scale--thus, the pyramids, the Roman aqueducts, the Suez and Panama Canals, the American railroads, the Great Wall of China--all were undertakings of such massive scale that only governments could provide the massive material and financial resources necessary to do the job.

Exploration and the new concepts it encourages have always been frightening to some and vulnerable to criticism by others. For example, a group called the Talavera Commission reported: "The committee judged the promises and offers of this mission to be impossible, vain, and worthy of rejection: that it was not proper to favor an affair that rested on such weak foundations and which appeared uncertain and impossible to any educated person, however little learning he might have."[1] That excerpt is from the Talavera Commission in Spain in 1491 considering a proposal by a fellow named Columbus, who wanted some financing for an exploration he had in mind.

Earlier in that same century, a Chinese admiral named Cheng Lo mounted a number of great voyages of discovery and trade around the rim of the Indian Ocean, including the East Coast of Africa. These expeditions were enormous enterprises, using the very best technology available. Each of Cheng Lo's ships displaced around 1,500 tons and carried a crew of about 500. The largest was about 450 feet long, as compared to Columbus' ship Santa Maria, which was 125 feet in length. But twelve years after the death of Ming Emperor Yung-low in 1424, his successor forbade the construction of ships for overseas voyages. By 1550, the conservative Confucian mandarins prohibited the construction of ships with more than two masts, lest they be used to explore the unknown. The spirit of exploration and enterprise in China was stunted for centuries to come by the lack of continuity of effort. And in my own country, when Congress was asked to appropriate funds for the exploration and eventual settlement of that part of the United States that was to become Chicago, New Orleans, San Francisco and other great cities and states, no lesser person than Daniel Webster voted against the idea saying that it would be a waste of the taxpayer's money because that territory, as everybody knew, had nothing but barren scrub cactus, deserts, high mountains, and uncivilized savages.

All of us, on the other hand, have had the privilege of being a part of an enterprise that has been unique in its willingness to deliberately explore the unknown--the exploration of space. The philosophy of our Nation's space program was best expressed by Robert H. Goddard, the great American rocket pioneer, who once said, "Real progress is not a leap in the dark, but a succession of logical steps."[2] And for the past twenty-five years--from Mercury through Gemini, Apollo, Skylab, and the Space Shuttle--successive U.S. Presidents and Congresses have supported an American space program built as a rational step-by-step extension of what came before. The next step, our

Nation's decision to build the Space Station is, in the words of Erik Quistgaard, former Director General of ESA, "another manifestation of your nation's capacity to create, to adapt and renew, which has shown itself in many ways throughout your history."[3]

Private sector investment and involvement in space actions is not new. The first logical commercial step took place 23 years ago when the American Telephone and Telegraph Company (AT&T) approached NASA to request that NASA provide launching services for two experimental communications satellites named TELSTAR. These satellites were launched into low earth orbit in 1963, the same year that the Congress passed the Communications Satellite Act. This Act established the Communications Satellite Corporation (COMSAT) as a quasi-government corporation to exploit the global potential of communications satellites. During this same period NASA's SYNCOM Program was underway to demonstrate the potential of the geosynchronous orbit for satellite communications. These factors converged with the launch of the first commercial (revenue producing) satellite into the geosynchronous orbit for COMSAT in 1965. In the ensuing years, there has been a significant growth in the use of satellites for communications into what has been estimated to be a $3.0 Billion dollar per year industry.

With the Space Shuttle an operational reality and the Space Station a defined national commitment, the tools, techniques and experienced people are available to assist industry in exploiting the microgravity of space to produce valuable products imbued with qualities impossible to achieve on the Earth.

Also for the first time, mechanisms are being established for lowering the technical and financial risks inherent in high technology space ventures. Recent government actions have reduced these risks to levels equal or close to those of conventional industrial high technology investments.

The latest thrust of the U.S. space program unfolded late in 1984 when NASA adopted and published its Commercial Use of Space Policy. The new policy invites and encourages entrepreneurs to establish and conduct businesses in space. With NASA's help and stimulation, space--until now almost predominantly the scene of government activities--is to become an arena for competitive, profit-seeking, dividend-paying, tax-yielding, jobs-creating private enterprises. The Policy was developed by representatives from NASA Headquarters and Field Centers in consultation with experts in industry and the academic community.

The fleet of four U.S. Space Shuttles has become operational. They offer commercial users, for the first time, the frequent and reliable roundtrip transportation to orbit required for profitable industrial operations. The Shuttles are suitable for carrying small research packages at low transportation cost. The Shuttles also can carry bulky industrial payloads which can be accompanied into orbit by up to three scientists, engineers, technicians or other specialists whose only major assignment in space is to tend the payloads.

microgravity, mixtures remain suspended during melting and solidification. This opens a new field of superconductors, eutectics and high strength alloys.

Two specific Shuttle experiments have moved beyond the basic research stage. Monodisperse latex spheres have been grown to the size of 18 microns with five times the uniformity of ground samples; spheres as large as 30 microns with less than 2% standard deviation from rounding have been produced as well. This MPS process is close to commercial scale-up.

The McDonnell Douglas/Johnson and Johnson Continuous Flow Electrophoresis System (CFES) has demonstrated a considerable improvement over conventional ground-based devices--500 times the throughput and five times the purity obtainable in the separation of living cells. Upcoming Shuttle flights of CFES will involve production of materials suitable for clinical testing.

Products with MPS commercialization potential are divided into three broad categories: (1) products which have a high value to weight ratio; (2) unique products which cannot be processed effectively on earth; and (3) products which can be more efficiently processed in space. The essential criteria for determining candidate products for commercial manufacturing in space is that they should be sufficiently light to minimize transportation charges and sufficiently valuable to insure that their market value offsets the costs attributable to transportation. Unique products could potentially create new markets or prove to be of such superior quality as to produce a high value to weight ratio. And in the third case, the value of a product should increase and its costs should decrease as its processing improves. A 400 to 1 improvement in the effectiveness of space processing is a realistic threshold for selecting candidate processes in this instance.

As a tool for the exploitation of MPS, the STS has the capabilities to meet the needed tasks; compiling the fundamental knowledge, developing useful processes and screening useful products. MPS is the area of greatest promise in the commercial exploitation of space and the cost of transportation is one of the most significant elements in the initial efforts. The planned Leasecraft and Space Station efforts will provide platforms to continue the exploitation of these potentials by providing larger, more sophisticated support equipment and prolonged processing time.

The private sector has begun to evidence a growing interest in MPS. NASA has signed agreements with McDonnell Douglas, Microgravity Research Associates, 3M, Martin Marietta Company, John Deere, Dupont, Inco, Honeywell, Grumman and Rockwell to pursue MPS activities. Discussions are being held with many other companies, both aerospace and non-aerospace, for further pursuit of MPS efforts. The majority of these efforts are focused on the type of research and development initiative outlined in the national Commercial Use of Space Policy and the National Space Strategy.

B. COMMERCIAL COMMUNICATIONS SATELLITES

The growth in communications satellites can best be illustrated by the growth in the number of commercial communications satellite launchings between 1965 and 1984. This history also shows two types of satellites evolving: the larger satellites of Intelsat using up to 50 transponders for the purpose of international communications traffic with limited usage for domestic traffic, and the smaller satellites tending toward approximately 24 transponders for domestic or regional communications traffic.

The growth can further be illustrated by the fact that in 1980 there were only three American companies in the communications satellite business, with nine comsats in orbit carrying 144 transponders. There are currently seven U.S. companies with 23 satellites totaling 472 transponders and by later this year the combined U.S. and Canadian comsat population could rise to 40 with about 1000 transponders.

C. OTHER SPACE APPLICATIONS

1. Earth Observations. Landsat orbits the earth at 438 miles, measuring such things as vegetation reflectance and moisture, sediment-laden water, and rock/soil differentiation. It is capable of geologic mapping, forest inventory, crop monitoring, water resource management, demographic studies and land use analysis.

In February of 1983, President Reagan signed a decision memorandum authorizing the U.S. Government transfer of its civilian land remote sensing satellite system to the private sector. During 1983 and 1984, both Houses of the Congress passed legislation which was signed by the President on July 17, 1984, becoming Public Law 98-365.

EOSAT is a joint venture partnership formed by Hughes Aircraft Company and RCA Corporation, for the express purpose of establishing a private sector U.S. Operational Land Observation and Data Service Program. The program includes the fabrication, integration, and launch of Landsats 6 and 7 on the Shuttle and establishment of a new ground system for command and control of the satellites and processing of unenhanced data to meet user requirements. The launch, in late 1985 on the European Ariane vehicle, of the first in a series of SPOT Satellites, will create a clear, serious challenge to U.S. dominance in commercial remote sensing from space. The French Government, through the Center National d'Etudes Spatiales (CNES), will retain responsibility as satellite operator; the marketing and distribution of the data are licensed to SPOT IMAGE which operates as a commercial entity.

The primary market difficulty facing remote sensing enterprises is the high cost of data gathering and distribution systems while competing with inferior but inexpensive alternative mechanisms.

2. Navigation and Mobile Systems. Many public and private sector organizations have, during the past decade, identified a need for mobile communications capability for a wide variety of purposes/markets.

Implementing the need for feasible systems to support public safety (emergency vehicles, search and rescue, civil defense, etc.) has been identified by the Congress as a "Requirement for Nationwide Continuity of Mobile Communications for Public Safety Purposes."[4] NASA has been involved for some time in low cost experiments utilizing the NASA ATS-3 and -6 satellites to demonstrate the ability of ten meter satellite antennae to function with terrestrial mobile units using off the shelf ground receiver hardware. Current research will make it possible by 1990 to launch 20 to 55 meter antennae necessary to provide spot beam ground coverage that is the next step in advancing these technologies. Launch and orbit insertion of systems of this size and complexity will be critical to the viability of any private sector program in this area and will be totally dependent on the availability of Space Shuttle launch services at reasonable cost. Venture capital is being raised and commercial applications are being prepared, or have already been filed with the Federal Communications Commission (FCC), for authority to build and launch these type systems by several potential commercial operators--Mobilesat, Skylink, Geostar, Collins Radio, each of whom anticipates that an investment up to $200 Million will be required.

A 1981 Citibank financial market study[5] projects private sector industrial data and voice market of $2½ to 3 Million by 1995 that would generate annual revenues in excess of $½ Billion and related annual Return on Investment (ROI) in excess of 20%. NASA has made similar projections. In November 1983, NASA and the Canadian Department of Communications (DOC) signed an arrangement to cooperate with industry in the definition of a space program that could lead to the development of commercial satellite service to meet mobile communications needs in both countries.

D. IN-SPACE (INFRASTRUCTURE) SERVICES

Heretofore, the private sector's involvement in space-related commercial activities has been in the fields of communications and, to a lesser degree, remote sensing and launching systems. It should be noted, however, that U.S. industry has several other opportunities for space-oriented, profit-making activities. In particular, the provision (through lease, sale, or other arrangements) of hardware and related integration services to support industrial research and product development activities has now been recognized as a potential revenue-producing business.

The best and most well known example of a private sector-provided in-space service is McDonnell Douglas' (MDAC) Electrophoresis Operations in Space (EOS) project. In this case, MDAC designed and built a piece of research hardware to support commercial research interests of the Ortho Pharmaceutical Company. In exchange, Ortho provides the expertise required to move this research through Federal Drug Administration clinical trials and ultimately into marketable pharmaceutical products.

Other aerospace companies have proposed variations of this theme: Ball Aerospace and Teledyne Brown Engineering have each considered private development of commercially-oriented experiment carriers for the STS payload bay; Fairchild's Leasecraft--a STS-launched, free-flying platform, would provide the basic spacecraft utilities for commercial research and manufacturing activities; RCA's proposed spacecraft bus similar to Fairchild's concept; and Space Industries, Inc.'s Industrial Space Facility (ISF) which would be available on a lease or service contract basis and provide a shirtsleeve environment for research, development, and production scale processing in space.

E. SPACE TRANSPORTATION AND RELATED SERVICES

The development of the eight foot diameter fairing for Delta in 1972 was the first instance of private sector investment in launch vehicle capability, followed closely by the development of the higher performance 3914 and the

IMPLEMENTATION

In implementing this policy, NASA is taking an active role in supporting commercial space ventures which are either new commercial high-technology ventures, new commercial applications of existing space technology, or commercial ventures resulting from the transfer of existing space programs to the private sector.

NASA is implementing initiatives to reduce the technical, financial and institutional risks associated with doing business in space.

1. Technical Risks. To reduce technical risks, NASA is supporting research aimed at commercial applications; easing access to NASA experimental facilities; establishing scheduled flight opportunities for commercial payloads; expanding the availability of space technology information of commercial interest, and supporting the development of facilities necessary for commercial uses of space.

2. Financial Risks. To reduce financial risks, NASA is continuing to offer reduced-rate space transportation for high-technology space endeavors; assisting in integrating commercial equipment with the Shuttle; and, under certain circumstances, purchasing commercial space products and services and offering some exclusivity.

3. Institutional Risks. To reduce institutional risks, NASA is speeding integration of commercial payloads into the Orbiter; shortening proposal evaluation time for NASA/private sector joint endeavor proposals; establishing procedures to encourage development of space hardware and services with private capital instead of government funds; and introducing new institutional approaches for strengthening NASA's support of private investment in space.

THE OFFICE OF COMMERCIAL PROGRAMS

The Office of Commercial Programs has become the focal point for NASA's commercial space activities. It has become the receiving station for inquiries and proposals pertaining to commercial space activities and is now NASA's prime channel for communication and negotiation with prospective commercial users of space.

Its primary objective is to provide a focus for an agencywide program to encourage U.S. private investment in commercial space ventures and to facilitate commercial application and transfer of existing aeronautics and space technology to the private sector.

The Office of Commercial Programs has established four major objectives for accomplishing its goal of expanding the level of private sector investment and involvement in space-related activities.

1. Establish close working relations with the private sector and academia to encourage investment in, and the use of, space technology.

To accomplish this objective the Office of Commercial Programs has emphasized two basic elements; the Centers for the Commercial Development of Space (CCDS) and cooperative agreements. In early 1985, the Office of Commercial Programs issued a request for proposals for CCDS. These Centers will perform basic space research activities which have commercial potential. In June, NASA received twenty-one responses to the request for proposals. Selected proposals are expected to be announced in early September.

There are several types of agreements being employed by the Office of Commercial Programs in working with the United States private sector.

Joint Endeavor Agreements - a cooperative arrangement involving no exchange of funds. Data and patent rights of the private sector are protected.

Launch Services Agreements where the customer launches his payload aboard the Shuttle supported by a standard package of services and provided with risk allocation, financial arrangements, patent and data rights guarded and other special services.

Technical Exchange Agreements. No flights are involved, but there is an exchange of technical information between NASA and the customer as a result of ground-based research. There is minimum expense to the company.

Industrial Guest Investigator. Here the company scientist collaborates on a NASA experiment. The company pays its own expenses and learns firsthand NASA methodology and NASA gains another viewpoint and augmented manpower.

2. Facilitate private sector space activities through access to available U.S. Government capabilities.

The agreements outlined above also serve as a mechanism for accomplishing this objective. Existing NASA hardware and facilities are made available to private researchers in the same manner that NASA's windtunnels are made available to the private sector portions of the Nation's aeronautics capability. The Office of Commercial Programs is augmenting the existing NASA flight experiment hardware capability and assisting in the establishment of an accessible research data base.

3. Encourage private sector investment that is independent of NASA funding.

The same mechanisms outlined above have been implemented to accomplish this objective. Other mechanisms will be implemented in conjunction with other government agencies to assist in the achievement of this objective.

4. Develop a Commercial Space Policy and oversee consistent NASA-wide implementation.

The NASA Policy was approved in late October 1984. The Office of Commercial Programs is in the process of establishing agencywide mechanisms to insure consistent application at each NASA installation.

TECHNOLOGY UTILIZATION PROGRAM

The wealth of aerospace technology generated by NASA programs is a valuable national resource and foundation with the potential for developing new products and processes. One of NASA's jobs is to translate the potential into reality by putting the technology to work in new applications through the instrument of its Technology Utilization Program within the Office of Commercial Programs.

The program coordinates the activities of technology transfer specialists located throughout the U.S. at 10 NASA Field Installations: seven industrial application centers, two state technology application centers and a computer software management and information center. These Installations provide information retrieval services and technical help to industry and state and local governments. The network's principal resource is a computerized storehouse of technical knowledge that includes more than ten million documents.

Staffed by scientists, engineers and computer retrieval specialists, these Installations provide three basic types of services: search data banks for technical literature relevant to client's needs; disseminate "current awareness" reports designed to keep client personnel abreast of the latest developments in their fields; and provide technical assistance in applying the information retrieved to the client's best advantage.

Other mechanisms employed in the Technology Utilization Program are a quarterly publication that informs potential users of new technologies available for transfer, and seminars and conferences that bring together NASA and industry personnel, a means of introducing non-aerospace firms to NASA, its technologists and its research and development activities.

These aspects of the new NASA initiatives closely follow very successful precedents established by NASA (and its predecessor agency, NACA) in its relations with the aeronautical industry. That industry benefitted and advanced significantly through the use of government research information and the use of government facilities. The Office of Commercial Programs adds new vigor to the translation of this tradition to the exploitation and utilization of space for commercial purposes through the three-pronged partnership linking the United States Government, United States industry and the domestic academic community.

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THE CANADIAN ASTRONAUT PROGRAM

by

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CANADIAN ASTRONAUT PROGRAM

INTRODUCTION

Within NASA there are three categories of astronauts; the commander and pilot, the mission specialist and the payload specialist. The commander and pilot are responsible for flight operations. The mission specialist has responsibilities that pertain to a specific mission. During the ascent and reentry he is the flight engineer, while on orbit he handles all RMS operations and all EVA activity. Part of his responsibility includes the payloads in the cargo bay but NASA is now sharing and delegating this to the payload specialist. The payload specialist, by definition, is responsible for a specific payload. They are generally career scientists who are experts in the particular field that relates to the payload. Ideally the payload specialist would be the principal investigator for the payload. The pilot and the mission specialist are career astronauts whereas the payload specialist depending on the payload, may only fly once.

Canada has two identified shuttle flights. The next Canadian flight shall carry the Space Vision System on the flight deck. This system will technically assist rendezvous and proximity operations. The following flight will concentrate on the medical aspect of man's adaptation to gravity in a series of experiments associated with Space Adaptation Syndrome. Canada presently has six Canadian astronauts who are candidates for these two flights, three who are technically trained scientists and three who are medically trained professionals. Because these candidates were selected with these payloads in mind they are in the real sense of the definition, payload specialists. However, the responsibilities of the Canadian astronauts do not exactly match the NASA classification of payload specialists because a major portion of their responsibility is to conduct a series of other experiments. On STS 41-G Marc Garneau conducted experiments for five teams of Canadian investigators in life science, space science and technology. This mode of operation will continue on future flights. The wide variety of experiments that originate from several disciplines precludes the possibility of the Canadian astronaut being a career expert on each experiment. He does however develop an expertise with respect to the experimental conditions of the scientific laboratory in space. This expertise is very essential in transfering and integrating, a ground based idea into the orbiting laboratory. He therefore develops a high standard of efficiency with respect to the scientific operation of experiments in space. Consequently the title payload specialist for a Canadian astronaut is not entirely suitable. Whatever the title, the role and responsibility of a Canadian astronaut is to conduct a series of coordinated experiments that will act in the national interest.

During this definition phase of the Canadian microgravity program (prior to Space Station) this role of the Canadian astronaut is very important. In order to determine the direction that the microgravity program will follow; for example, on what material processing method should we concentrate, a series of small experiments will have to be conducted. Although some will be in the cargo bay, most will be in the mid-deck or possibly in the European Spacelab. These experiments necessarily should be designed with a man in the loop and scientific iteration should be encouraged in situ. In many cases this type of operation will allow the next scientific step to be taken on the same flight instead of waiting for the next chance to conduct an experiment in space. The lead time for flying experiments in space is so long that one should design "hands on" type experiments so that maximum scientific information is obtained on each flight. Obviously the decision making process through the definition phase of the Canadian microgravity program would be greatly accelerated. The final result would be that Canada would make more efficient use of Space Station.

The following viewgraphs summarize the goals, objectives and present status of the Canadian Astronaut Program.

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THE CANADIAN ASTRONAUT PROGRAM

- BEGINNINGS:
  - AN INVITATION FROM NASA IN 1982 AS A DIRECT RESULT OF THE CANADARM PROGRAM
  - FORMALLY ACCEPTED IN 1983
  - 2 FLIGHTS IDENTIFIED
  - 6 ASTRONAUTS SELECTED IN DECEMBER '83 FROM 4300 APPLICANTS

- OBJECTIVES:
  - (I) TO UNDERTAKE TWO CANADIAN EXPERIMENTS IN SPACE WITH THE SPACE SHUTTLE
    - SPACE VISION SYSTEM (SPACE TECHNOLOGY)
    - SPACE ADAPTATION SYNDROME (LIFE SCIENCES)
  - (II) TO UNDERTAKE OTHER EXPERIMENTS IN SPACE INVOLVING CANADIAN ASTRONAUTS
  - (III) TO INCREASE THE GENERAL PUBLIC'S AWARENESS OF THE CANADIAN SPACE PROGRAM AND ITS BENEFITS
  - (IV) TO ENCOURAGE YOUNG CANADIANS TO PURSUE CAREERS IN SCIENCE AND TECHNOLOGY

- FIRST FLIGHT
  - UNEXPECTED INVITATION IN EARLY 1984 FOR AN EXTRA FLIGHT
  - M. GARNEAU FLEW IN OCTOBER '84 ON STS 41G AS CANADIAN PAYLOAD SPECIALIST
  - CONDUCTED EXPERIMENTS FOR 5 TEAMS OF CANADIAN INVESTIGATORS IN LIFE SCIENCES, SPACE SCIENCES, SPACE TECHNOLOGY

Canada

THE CANADIAN ASTRONAUT PROGRAM

- PRESENT ACTIVITIES:
  - FOLLOW-UP TO STS-41G
  - PREPARATIONS FOR NEXT TWO FLIGHTS
  - SUPPORT TO SPACE STATION STUDY ACTIVITIES (INCLUDING RADARSAT)
  - PARTICIPATION IN NASA LIFE SCIENCE PROJECTS (E.G. SPACELAB)
  - INVESTIGATION INTO REQUIREMENTS FOR A CANADIAN SPACE EXPERIMENTS CARRIER SPACECRAFT
  - PUBLIC APPEARANCES
  - TRAINING FOR ROLES AS PAYLOAD SPECIALISTS

- TRAINING
  - STUDYING SPACE SHUTTLE SYSTEMS AND OPERATIONS
  - PARTICIPATION IN PREPARATIONS FOR LIFE SCIENCES EXPERIMENTS
  - PARTICIPATION IN SVS HARDWARE & SOFTWARE DESIGN REVIEWS AND EXPERIMENT PLANNING
  - PARTICIPATION IN PREPARATIONS FOR OTHER EXPERIMENTS SELECTED
  - INCREASING BACKGROUND KNOWLEDGE OF EARTH SCIENCES, SPACE SCIENCES, SPACE TECHNOLOGY
    (SIGNIFICANT SUPPORT HAS BEEN RECEIVED FROM UNIVERSITIES AND OTHER GOV'T DEPARTMENTS WHO HAVE PROVIDED GUEST LECTURERS)

CANADIAN PAYLOAD SPECIALIST'S EXPERIMENTS ("CANEX") ON STS-41G

- SPACE ADAPTATION SYNDROME SUPPLEMENTAL EXPERIMENTS
  DR. D. WATT, MCGILL UNIVERSITY AND 6 CO-INVESTIGATORS IN 4 AGENCIES

- SUN PHOTOMETER EARTH ATMOSPHERE MEASUREMENTS
  DR. W. EVANS, ENVIRONMENT CANADA AND 10 CO-INVESTIGATORS IN 4 AGENCIES

- ORBITER GLOW MEASUREMENTS
  DR. D. KENDALL, CANADA CENTRE FOR SPACE SCIENCE AND 11 CO-INVESTIGATORS IN 5 AGENCIES

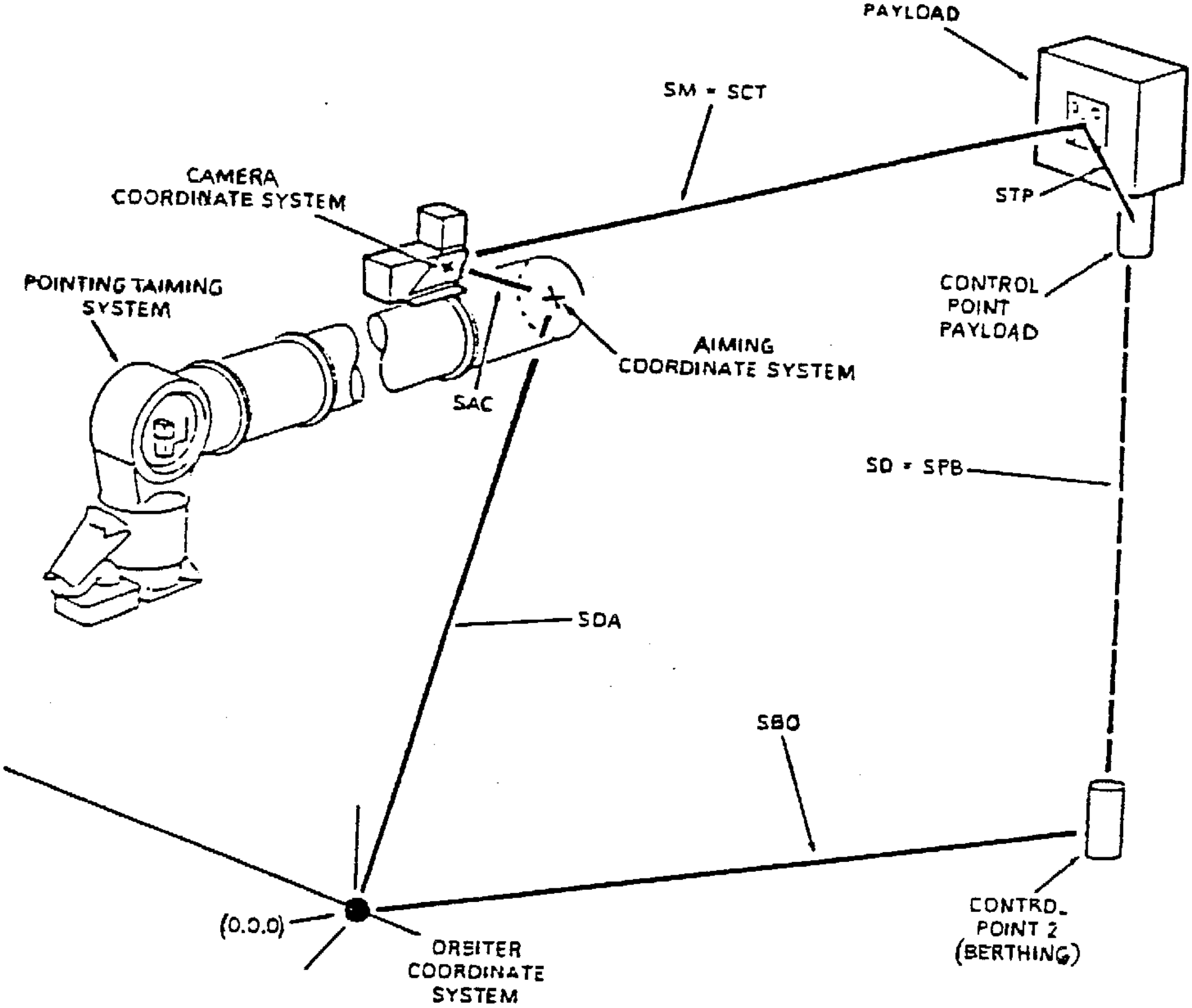
- ADVANCED COMPOSITE MATERIAL EXPOSURE
  DR. D. ZIMCIK, COMMUNICATIONS CANADA AND 3 CO-INVESTIGATORS IN 3 AGENCIES

- SPACE VISION SYSTEM EXPERIMENT DEVELOPMENT TESTS
  DR. L. PINKNEY, NRCC AND 3 CO-INVESTIGATORS

I.E. MARC GARNEAU ACTED AS PROXY-INVESTIGATOR ON BEHALF OF 38 INVESTIGATORS REPRESENTING 17 AGENCIES

SPACE VISION SYSTEM

The Major Payload of the Second Canadian Flight



SCT = SM	MEASURED 6 DEGREES OF FREEDOM (CAMERA TO TARGET ARRAY)
SAC	AIMING SYSTEM TO CAMERA DISPLACEMENT AND ATTITUDE
SDA	ORBITER COORDINATE SYSTEM TO AIMING SYSTEM DISPLACEMENT AND ATTITUDE
SBO	CONTROL POINT 2 TO ORBITER COORDINATE SYSTEM DISPLACEMENT AND ATTITUDE (ENTERED USING D&C PANEL)
STP	TARGET ARRAY TO CONTROL POINT 1 DISPLACEMENT AND ATTITUDE (ENTERED USING D&C PANEL)
SPB = SD	DISPLAYED DISPLACEMENT AND ATTITUDE OF CONTROL POINT 2 WITH RESPECT TO CONTROL POINT 1 COORDINATE SYSTEM

NOTE THE GENERAL SOLUTION TRANSLATION IS SIMILAR TO THE BERTHING TRANSLATION EXCEPT THE SBO AND STP VECTORS CAN BE DEFINED USING THE D&C PANEL AND THE SD VECTOR SENSE IS REVERSED

GENERAL COORDINATE SYSTEM SOLUTION TRANSLATION

EXPERIMENTS PLANNED FOR SECOND CANADIAN SHUTTLE MISSION

SVS

SPEAM -2
Sun Photometer
Earth Atmosphere
Measurements

MELEO
Material Exposure
in Low Earth Orbit

PARLIQ
Phase Partitioning
in Liquids

DICOLM
Diffusion
Coefficients
of Liquid
Metals

OGLOW-2
Orbiter Glow
Studies

SATO
Space Adaptation
Tests & Observations

THE COMINCO ELECTRONIC MATERIALS STRATEGY
FOR SPACE STUDIES

by

R.F. Redden and A.B. Bollong
Cominco Electronic Materials Division
Cominco Limited

THE COMINCO ELECTRONIC MATERIALS STRATEGY FOR SPACE STUDIES

R.F. Redden, Development Manager
A.B. Bollong, Research Physicist
Cominco Electonic Materials Division
Cominco Ltd., Trail B.C.

All studies documenting the economic future of commercial opportunities in space predict that pharmaceutical, semiconductor and glass production will be multibillion dollar businesses by the year 2000[1,2,3]. Cominco Electronic Materials Division, the only commercial producer of high purity semiconducting crystals in Canada, is conducting exploratory research in low gravity environments. All comments in this discussion are related to bulk crystal growth as opposed to the various epitaxial or thin film techniques.

Cominco has for many years publicly expressed interest in microgravity research on compound semiconductors. A number of existing Cominco EMD products have less than ideal properties which can be partially attributed to the effects of gravity driven convection, density segregation and impurities. The object of space related research is to determine whether improvements in device performance can be correlated with producing single crystal materials in low gravity and if the cost of processing can be justified by the device improvements.

Cominco's interest in microgravity research was recently supported by funding from NRC to investigate the effects of rapid directional solidification of CdHgTe in a low gravity environment. Collaborating with Cominco on this project are DSMA ATCON of Toronto and SED Systems of Saskatoon. All activities are coordinated by the NRC Canadian Centre for Space Sciences.

Analyzing the products which comprise the bulk semiconductor substrate market is important when prioritizing research in space. The categories which we have defined as important include market potential, value added and the current material deficiencies. It is important to know that a large market will exist so that a small niche market could be created for the space processed material. Current sales value was defined in terms of price/kg because of payload weight constraints. Knowledge of current material deficiencies is required to determine whether gravity related phenomena limit device performance.

Presently the most important semiconductor substrates in terms of annual sales are Si, GaAs, Ge, InP and CdHgTe, with the GaAs and InP markets expanding the most rapidly. Table 1 shows that Si maintains the lion's share of the substrate market. Si substrates account for 5% of the total solid state device cost which currently amounts to $20 billion. One important observation is that for the top five semiconducting crystals, the average selling price is inversely proportional to the annual total sales. This relationship, at least in part, results from the market demand and high production capital costs for InP and low production yields for CdHgTe.

TABLE 1 WORLD SEMICONDUCTOR MATERIALS MARKET 1984 VALUES

Bulk Single Crystal Wafers	Annual Sales (US$ x 10^6)	Feed Cost/Kg (US$)	Ave Selling Price (US$)	Material Deficiencies
Si	1,000	65	1,300	Satisfactory
GaAs	75	450	20,000	Uniformity, Stoichiometry
Ge	65	600	8,000	Uniformity*, Purity
InP	10	1,000	50,000	Availability, Size, Purity
CdHgTe	5	600	1,000,000	Homogeniety, Size

* For particular applications such as radiation detectors

Essentially all solid state devices utilize semiconductors in single crystal form. Therefore crystal growth is important. The methods of bulk crystal growth can be categorized as techniques of vapour growth, unseeded melt growth, seeded melt growth and solid state crystal growth. The basic methods are modified to enhance their application to specific materials or classes of materials. There is a strong artistic component in crystal growth and as such, the development of processes to achieve useful products has relied heavily on empirical engineering[4].

The elemental semiconductors, Si and Ge, are produced commercially by the techniques of Czochralski and float-zone. All commercially significant compound semiconductors except CdHgTe are congruently melting compounds. These products are best grown by the techniques of Czochralski or Bridgman. Czochralski grown III-V compounds containing As or P use a liquid encapsulant to prevent the loss of the highly volatile component. CdHgTe is grown primarily by solid state recrystallization techniques.

The effects of low gravity processing will not be discussed in the following sections as this subject has been treated by others. The remainder of this paper will focus on our expectations for low microgravity processing by describing three compound semiconductors which are produced by Cominco.

Our spirit for conducting industrial space based research is one of cautious optimism. Short term benefits cannot be measured in economic terms, they must be of scientific value. One of the more important commercial benefits from space based research may well be an improved understanding of the processes on earth rather than developing actual space manufactured goods. This is not to say that such products will not be developed; on the contrary, it is safe to say that probably very few have any idea as to what is and will be possible.

If microgravity research tests are to be successful and cost effective, it is imperative that the process and the equipment are fundamentally well understood, at least in an earth environment and that an intelligent attempt is made at understanding some of the added pitfalls introduced by operating in space. This point cannot be over emphasized because one does not get many chances to correct errors of judgement. CdHgTe is a fairly good example of that type of product.

CdHgTe is the exception to the Czochralski rule. It is the most widely used high performance infrared detector material. It is a psuedo binary compound of the components CdTe and HgTe. Ninety percent of all bulk CdHgTe is grown using the Quench/Recrystallization technique. In this process, the melt is cooled to form a fine grained, dendritic ingot. Prolonged annealing at temperatures below the melting point subsequently converts the ingot to a single crystal.

To maintain macroscopic uniformity it is necessary that the compositional extremes represented by the dendritic and interdendritic phases are held within a relatively short diffusion distance of each other. The large separation of the liquidus and solidus lines in this system dictate that there will always be pronounced segregation of HgTe during growth under equilibrium conditions. It is therefore necessary to rapidly solidify the melt in order to limit segregation.

The effect of gravitation on the resultant crystal homogeneity can be understood from a description of the solidification process. In the Cominco process, stoichiometric amounts of Hg, Cd and Te are placed in a quartz ampoule which is evacuated to less than 1×10^{-6} Torr and sealed. The ampoule is gradually heated to a temperature above the liquidus temperature for the desired composition. The melt is allowed to homogenize for a period of time before it is lowered into a cold region of the furnace.

During cooling a region around the tip of the ampoule freezes. Heat released during solidification contributes to the total heat content. The poor thermal conductivity and emissivity of CdHgTe and poor thermal conductivity of quartz causes wall cooling to take initially and the melt/solid interface becomes conical or paraboloidal.

The system is not allowed to equilibrate and therefore the excess segregated HgTe cannot dissolve into the CdHgTe melt and sinks to the bottom of the parabolic well by density stratification. The resulting radial composition profile is then exaggerated from that expected by the interface curvature. The effect of HgTe density stratification strongly affects CdHgTe radial composition on wafers of greater than 10 mm diameter.

CdHgTe has a mature device technology which permits near theoretical detection of radiation in the two atmospheric windows 2-5 microns and 8-14 microns. Bulk grown CdHgTe is limited in size and homogeneity. Emerging focal plane devices require large, more uniform wafers. Space related research may be justified on the basis of economics if improvements are significant and for increasing the metallurgical understanding of the process and technology.

A Cominco program for space research also includes Ge float zone refining. Knowledge of this technique is of fundamental importance to space processing. Float zone refining and crystal growth can take advantage of the potential benefits of microgravity and is a basic process for other materials.

In the float zone technique a molten zone is established in a rod of material and the molten mass is contained by the surface tension of that material. Under terrestrial conditions gravity is the major hydrodynamic force, but under microgravity conditions surface tension becomes dominant and zone stability is increased. It may be possible to significantly increase the diameter of crystals grown by this technique. Float zone growth is a containerless process and the potential for contamination is reduced.

The Czochralski growth of Ge crystals is a very mature technology, yet for some applications, poor and inconsistent yields are attributed to contamination from various sources; the source material, crucibles, gases and the Czochralski equipment[5].

Ge crystals used for the fabrication of gamma radiation detectors are required to have a purity and crystal perfection unsurpassed by any other material. They must have a net electrically active impurity concentration less than 25 parts per trillion, and be free of any charge trapping defects.

A recent market study estimated the potential world Ge market for gamma ray detectors at 750 kg/year[6]. The present demand is for crystals of 50-60 mm diameter. This is the present limit for float zone Ge crystals on earth. In order for microgravity grown crystals to compete in the existing market, they would have to be of a superior quality.

The prospect of growing Ge crystals in space is attractive because of containerless processing, ultra-high vacuum environment for outgassing volatile impurities, reduced thermal gradients, and increased molten zone stability.

GaAs space related research is low on Cominco's list of priorities at this time. This is not to say that valid microgravity research cannot be applied to this compound but rather that Cominco could derive a better economic return from terrestrially based process studies. Maintaining stoichiometry, reducing thermally induced defects and reducing impurity concentrations are of paramount concern. The introduction of strong magnetic fields during Czochralski crystal growth for suppressing convection has shown considerable promise for making higher uniformity GaAs[7,8,9]. High concentration isoelectronic doping has also proven to reduce crystal structure defects[10]. A recent Japanese study combining the latter two innovations demonstrated 'dislocation free' GaAs[11].

The rate of GaAs market expansion forces our outlook to be in the real world. The business is so capital intensive that real time cost recovery is essential to remain buoyant. We believe the most important advancements of materials science in the III-V compounds will derive from a maturation of the terrestrial research. A small niche market may be created for improved space processed GaAs, but improvements in terrestrial processing within the next 15 years will increase device yields.

For the record, the technique proposed for GaAs growth is a solution based liquid phase electroepitaxy process, patented by Microgravity Research Associates. LPEE operates at 800-950°C, well below the melting temperature of GaAs (1238°). An electric current is passed through the molten solution and the seed. The Peltier thermoelectric effect causes cooling at the seed thereby causing supersaturation and growth occurs in epitaxial layering[12].

NASA is providing seven free shuttle flights for this research. The last flight, scheduled for 1991, will try to demonstrate MRA's commercial viability by producing bulk crystals of GaAs. The expected cost of this product is estimated at $450,000/kg in 1992 to $250,000/kg in 2000. MRA feels that it must produce 20 kg of GaAs annually to be profitable[13]. Twenty kilograms is equivalent to the current daily production of GaAs at Cominco.

In conclusion, Cominco views the short term commercialization of space as a study of processes in an environment which will aid the understanding of terrestrial processes. Although this information will undoubtedly lead to an improvement of crystals on earth, the significance of such an improvement for device applications remains unresolved.

Terrestrially grown crystals are not perfect for a variety of reasons. These include impurity levels, impurity segregation, thermally induced defects, stoichiometry and mechanically induced defects. Microgravity can offer help by reducing convection and density segregation but this is not the solution to all problems. It cannot compensate for poor planning, inadequate design engineering or impure feed. Innovative designs have already partially overcome the adverse effects of gravity more economically than space processing might be expected to achieve.

A future trend toward space processing is inevitable. We must not be too short sighted in our approach to space commercialization. Spin off products are bound to result from a long term study program. The demand for higher purity, more perfectly crystalline materials is a constant in the semiconductor industry. Space processing of commercial products may show unexpected progress but for now basic research should be emphasized.

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QUEEN'S UNIVERSITY MICROGRAVITY PROGRAMME

by

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hardware etc. can be very costly. What it does is to reinforce the statement, "do not attempt anything in space until you have thoroughly researched in at 1g, and still have a good reason to do so".

In crystal growth processes uncontrolled liquid transport can lead to a wide variety of crystal property variations. However, Lorentz damping i.e. the presence of a magnetic field transverse to the major axis of a specimen, can work wonders to reduce/remove convection. Microgravity experiments can best be used to:

a) generate reliable data for use in "1g" materials processing, e.g. obtain good values for liquid diffusion;
b) investigate the "weak" transport forces, e.g. Marangoni forces;
c) remove buoyancy-induced transport in particular crystal growth processes, e.g. provide a stable environment in the liquid-phase growth of large crystals, or in electrophoresis, to remove buoyancy effects which can arise from temperature gradients, mass flow due to joule heating and sedimentation of the separated constituents.
d) exploit the intrinsic properties of "space", e.g. very low pressure.

The most mysterious of these has been Marangoni transport, namely the response of liquid bodies to any gradients in free-surface interfacial energy as a result of temperature or concentration. The last fifteen years, particularly the last five, have seen a detailed evaluation of Marangoni effects so that, in most projected space situations, these influence may be modelled accurately.

2) Microgravity Research at Queen's University

The Queen's Programme is concerned primarily with three broad areas: -

a) immiscible alloy phenomena;
b) composite growth (monotectics and eutectics);
c) diffusion studies; and
d) the degradation and repair of materials in space.

Immiscible Alloys and Composite Growth

Items a) and b) have been the subjects of our "Get-Away Special" project and have involved us in the design and construction of two proto-type furnaces and the control and data recording equipment. These consist of: -

(i) Isothermal Furnace

The specimen is at the common focus of a pair of quartz-halogen lamps. This arrangement permits heating to 850°C at 300-400°C/min, good temperature control (± 0.5°C), to a maximum temperature of 950°C and a specimen with maximum dimensions of 9 mm diam. x 15 mm length. The cool-down can be varied at will. A planned variant is to maintain a temperature gradient through the specimen to provide a minimum energy gradient furnace.

(ii) Gradient Furnace

Three heating elements permit close control of the temperature gradients. The furnace has been designed to take a specimen 5 mm diameter x 100 mm length. The maximum operating temperature is about 950°C and the maximum temperature gradient is at least 100°C/cm. This would depend on the sample properties and geometry and available power.

(II) Swedish Collaborative Programme

The Queen's group is collaborating with Professor Hasse Fredricksson in an E.S.A. Maser rocket flight, possibly in October 1986. The systems selected are those which form a microstructure of plate-like primaries in a eutectic matrix.

(III) Liquid Diffusion Experiments

A number of experiments were proposed in response to a request from the Canadian Astronaut Programme Office. These were designed to be relatively inexpensive and provide a series of activities for the astronauts to carry-out arranged in a hierarchy of complexity. We were fortunate in that one of the proposed experiments was selected for development. This is concerned with simple experiments to measure various aspects of diffusion in liquids, such experiments tend to be bedevilled with unwanted convection. The experiments involved will lead to determinations of

a) bulk diffusion
b) thermotransport
c) electromigration

The data should be of considerable value in materials processing on earth since, to date, little or no good diffusion data for liquids has been available. In addition, the data should permit a critical evaluation of some of the theory of the structure of liquid metals.

(IV) Materials Joining in Space

Queen's is currently in contract negotiations with private industry to examine various aspects of materials joining in a microgravity and, possibly, in a micro-pressure environment. This work takes note of the fact that a suggested role for Canada in the Space Station is to provide repair and servicing facilities for the mini-rockets which are to shuttle instruments and materials to and from the free flying platforms and the Space Station. N.A.S.A. is reported to be taking a very conservative point of view and so will probably require that only metal structures be used.

3) The Prospects for Microgravity Materials Processing

It has been noted on many occassions that microgravity science and technology is still in its youth. Maturity will only come with experience but gaining that experience is costly as may be seen from the development budget of N.A.S.A. In Canada, the requests for such funds are in direct competition with funding requests for highly desirable social programmes e.g. health and welfare. As a result, when politicians are asked for funds for micro-gravity studies it is relatively easy to plead poverty because of other commitments. As a result, it is initially necessary for the microgravity users, i.e. scientists and engineers concerned with understanding and exploiting "gravity" as a materials-processing parameter, to come together and develop a unified view of priorities and then press the politicians to see the merits of well-considered proposals since it is only by becoming involved in the political process that we have any chance of helping Canada to develop a realistic and utilitarian space presence.

THE HONEYWELL/NORANDA PROGRAM FOR METAL ORGANIC CHEMICAL VAPOUR DEPOSITION OF GALLIUM ARSENIDE IN SPACE

by

D.B. Reid
Advanced Technology Centre
Honeywell Canada

Blake Reid
Honeywell Canada

The Honeywell and Noranda Program for Space Processing of Gallium Arsenide

I'm going to start off by giving you a brief summary of what it is I'm going to talk about. First, I'll describe the work carried out jointly by Honeywell and Noranda, the Ontario Research Foundation and T.A. Croil Associates, in the first phase of NRC's Space Station Industry Joint Endeavor Program. I'll briefly review the project objectives, say a few words about how we came to select gallium arsenide and MOCVD as our target material and process, and then outline our strategy and plan for a multiphase program leading to possible space commercialization of this technology. I'll wrap up by outlining the approach which we propose to take for the next phase of the program.

Honeywell Canada became involved in the Space Station Joint Endeavor Program in June of last year when we teamed with T.A. Croil Associates, a Toronto based consulting firm, to respond to NRC's RFP for the first phase of this program. Our submission lead to a contract award in December '84 with T.A. Croil acting as prime contractor and project coordinator. The project was completed in spring of this year with delivery of the final report to NRC. As you are aware, this project had three main objectives:

1) To identify a material which could benefit commercially from processing on the space station.

2) To identify Canadian companies which have an interest in space R&D related to the selected material and process.

3) To establish a teaming arrangement between at least two of these companies and to prepare a plan for a joint R&D program leading to possible commercialization of the selected material/process in space.

With respect to the first objective, four criteria were used in the selection of a suitable material. First, the material must be of strategic importance to the Canadian economy with potential for capturing a larger share of a growing market. Second, it should be of major commercial interest to the participating companies. Thirdly, it should encompass advanced state-of-the-art technology so that resulting products will not become obsolete by the time space manufacturing becomes a reality. Fourth, the selected material should have a reasonably good chance of benefiting one way or another from space processing.

With respect to Honeywell's interest in this program, we, as one of world's leading manufactures of computer and aerospace and defense systems, we don't just manufacture electrostatic air cleaners and thermostats, we would assume the role of consumer rather than producer of any space-produced material. In addition, we would support a space materials processing operation by developing suitable instrumentation and control systems. Naturally, in our search for candidate materials and technologies, we focused on the opto-electronic materials area.

After a comprehensive survey of the space materials processing field and careful assessment of technologies involved, we selected thin film gallium arsenide [GaAs] as the target material and Metal Organic Chemical Vapor Deposition, or MOCVD, as the target process. It is estimated that by 1990, the total world market will approach $1-billion for bulk GaAs and $5-billion for GaAs semi-conductors. Further, it is estimated that Canada could potentially gain about a 10% share of this market, that is approximately $500-million by 1990.

Gallium arsenide is frequently touted as the next generation semi-conductor. It has several advantages over silicon which include:

1) Use in digital IC's, where it offers higher switching speed. This is because its electron mobility is more than five times higher than that of silicon.

2) It has superior optical properties. It is used as the base material for optical devices such as lasers and photo detectors. Because of its electronic and optical properties, it is used in integrated optoelectronic devices, in which the optical and electronic components are fabricated on the same chip.

3) GaAs devices can be operated at high frequencies, namely in the microwave and millimeter wave region.

4) It has a higher tolerance to radiation. This is especially important for military and space applications, where radiation-hardened equipment is often required.

GaAs is also by far the most technologically mature of all "leading-edge" semi-conductor materials.

With respect to the process, MOCVD is a very recently developed epitaxial technique. It has potential to become a commercial scale process, and because of its relative newness, has scope for improvements leading to more efficient use of reactant material, better uniformity and lower defects. While it is difficult to be certain about the benefits of GaAs MOCVD in space, there appears to be a reasonable probability that these improvements could be more effectively realized in space, or at least through results of space based R&D. This issue will be addressed in detail in the next phase of the program.

Honeywell has a vested interest in GaAs products and a recognized capability in GaAs related technologies and applications. Honeywell is one of the world's leading suppliers of sensor-based aerospace and defense systems. Honeywell Canada, through the Advanced Technology Center in Toronto, is actively developing new integrated multi-sensor systems for the world's A&D,

aerospace and defence markets, and is currently transfering technologies from our parent company in the U.S. to support this thrust. High speed VLSI is a fundamental building block of our product programs, and gallium arsenide IC technology, in particular, is viewed as essential to systems in which large volumes of sensor data must be processed in real-time. We've established links with Honeywell's Physical Sciences Centre in the U.S. to transfer GaAs technology into the ATC to support our Canadian program, including space station effort. PSC is very active in development of semiconductor technologies based on III-V compounds, with emphasis on GaAs. To support this program, scientists at the Physical Sciences Centre have developed a leading edge capability in MOCVD as well as Molecular Beam Epitaxy, or MBE. PSC is also working toward a manufacturing capability in GaAs IC's, and has recently established a pilot production line in GaAs gate arrays and random access memories (RAMs).

Turning to the second objective of the project, we contacted about 100 companies in our attempt to find a suitable partner for the joint venture. Not surprisingly, many of the companies contacted had never thought of space processing. Some doubted the viability of space processing as a business venture. A few expressed enthusiasm about the prospect. All in all, these contacts served the purpose of alerting Canadians, Canadian industry to the potential of space processing. The search concluded happily with Noranda and the Ontario Research Foundation joining in the team. Noranda is actively involved in the production of high purity elements compounds and optoelectronic materials and compliments Honeywell in this program as it acts as the "supplier" member of the team. ORF, which plays a consulting role, is heavily involved in the research of optoelectronic materials processing.

The team proceeded to perform background studies needed to develop a plan for follow-on R&D and possible space commercialization of GaAs MOCVD. Honeywell reviewed the hardware and instrumentation for space experiments; Noranda reviewed the space experiments on electro-optic materials and ORF reviewed the land processes for electro-optic materials.

Under the direction of Tom Croil, the team then examined the state-of-the-art of GaAs MOCVD and its scope for space processing. During the course of this examination, the team recognized that material processing in space carries with it a high risk and a high price tag.

Since the issues of technical merit, market potential and cost benefit of space processing remain to be resolved, the team recommended the following strategy.

1) Select technology that is developing and shows great promise. MOCVD in our view is such a technology and GaAs is a material of growing importance.

2) Adopt a phase structured program. Each phase should be justifiable on a stand-alone basis, independent of whether space manufacturing is eventually achieved or not and the program

should be structured so that a decision can be made on completion of each phase as to whether subsequent activities should be undertaken.

3) In the earlier stages of this program, the space environment should be used primarily as a means of improving the land-based system by gaining insight into the processes under investigation. At the same time, space research will provide new insight into the feasibility of manufacturing in space.

In accordance with the strategy, we proposed the following phases leading to space commercialization: The first phase is a Preliminary Definition Study. The purpose of this phase is to resolve the technical, market and financial issues of MOCVD gallium arsenide processing in space.

The second phase is the experimental phase. It involves both land and space experiments, where the space experiments would be supported by extensive land-based research.

Land-based research is expected to be crucial to the success of this program as space experiments will be costly and limited in number due to the high level of competition for space on the shuttle. In this reguard, the U.S. recently announced the establishment of the Microgravity Materials Science Laboratory at the NASA Lewis Research Center. The purpose of this lab is to support space materials programs through ground-based R&D. It would be available for use at no charge to U.S. industrial, university and government researchers. A similar Canadian facility could be of significant value to the successful completion of the experimental phase.

In the third and fourth phases of this program, we have planned for the establishment of first pilot and then commercial operations. The Commercial Phase is scheduled to commence at a date which corresponds with the launch of the Space Station.

We have submitted a proposal recently to NRC to carry out the Preliminary Definition Phase. In this phase, Honeywell will assume the role of prime contractor and act as the overall program manager. Mr. Tom Croil will act as project coordinator as part of the Honeywell management and technical team. Noranda Inc. will be the prime subcontractor, and Ontario Research Foundation will provide consulting assistance in optoelectronic materials processing. In addition, we shall seek to involve various universities in this project and will continue to support the effort through technology transfer from Honeywell's Physical Sciences Centre in the U.S..

The statement of work of this proposal comprises four major tasks to be carried out over a period of six months. The first task is an in-depth, technical assessment of the benefits of space processing of GaAs. The second task is a market analysis. The third task is devoted to analysis of the financial aspects of the program, and the fourth task is for the preparation of preliminary specifications for land and space experiments to be carried out in Phase II.

We're ready to start and awaiting the approval of NRC.

edited by Amanda J. Brown
transcribed by Pippa Wysong

IMPORTANCE OF MARANGONI CONVECTION ON THE DESIGN OF A MULTIPURPOSE ELECTRIC FURNACE FOR MATERIAL PROCESSING IN SPACE

by

G. Saintonge and A. Poirier
MPB Technologies, Inc.

IMPORTANCE OF MARANGONI CONVECTION ON THE DESIGN OF A MULTIPURPOSE ELECTRIC FURNACE FOR MATERIAL PROCESSING IN SPACE

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H9P 1J1

ABSTRACT

Material processing in space has been a dynamic research activity in the past few years and promising results have been obtained. However the requirements imposed by space experiments are preventing industries, universities and research centers to fully exploit the possibilities of material processing in a microgravitational environment. A multipurpose electric heating apparatus can facilitate the accessibility of space since the experimenters would not have to worry about designing and constructing a space qualified furnace for their own experiment. This would result in a reduction in cost and lead time. The purpose of this article is to identify requirements for a multipurpose heating facility. The discussion focuses on the Marangoni convection.

1.0 INTRODUCTION

Soon after the birth of the space age, one began thinking about the possibilities of materials processing in a low gravity environment, as can be provided by orbiting satellites, and started dreaming this gold mine in the sky. For the past few years, many experiments were conducted in a microgravitational environment on materials processing in general and promising results were obtained. However, before material processing in space could become a successful industrial venture, three periods can be identified:

a) Detailed study of the influence of gravity upon materials processing;

b) Conduct of experiment in space, the results of which could be of great value for manufacturing on earth;

c) Manufacture of special materials for terrestrial use which cannot be produced on earth with the desired properties.

In planning materials science experiments in space, one must take into account the constraints associated with the type of space platform to be used, each one having its own level of microgravity, its own limitation as regards time, power, energy, cooling, data acquisition and safety regulations. Even in the case of the simplest and best known material science experiments, space implementation will require much extra work. The overall cost of the experiments, their long preperation time and the small number of flight opportunities make it essential to maximise the scientific or commercial return while minimizing the cost.

In order to meet those stringent requirements [1], a research program must address the scientific problems in a systematic way from simple and inexpensive experiments followed by experiments with increasing degrees of sophistication. The technology used should be relatively standard so that its behaviour in space can be predicted, otherwise the experimenters will be testing simultaneously the equipment and the material processing which is certainly not desirable. The heating facility design must avoid some of the technical problems mentioned in reference [1] and take into account the physical problems (e.g. convective instabilities, thermal and concentration gradients, Marangoni instabilities) associated with material processing.

This favors the development of a conservative multi-purpose heating apparatus. It is important to understand that such a facility would be not only useful in a large scale configuration but also in small scale as in GAS can or in a Canadian Space Carrier. Furthermore, the construction of a small scale multi-purpose space-borne heating apparatus should be the first step toward the construction of a larger system. It would enable Canadian companies, universities and scientific institute which are interested in material processing in space to use this multipurpose facility as an inexpensive and quick tool to start the development of their own program.

It is the purpose of this article to identify some of the requirements that a multipurpose heating facility must meet. The discussion focuses primarily on the problems associated with the surface tension-driven convection called the Marangoni convection. As long as free surfaces exist, Marangoni convection is established. A carefully designed heating apparatus will be capable of limiting the Marangoni convection to a minimum. It is thus important to understand as much as possible the physics of this phenomenon.

Section 2.0 defines the major problems of material processing on earth as well as its major advantages and shortcomings in space. Section 3.0 discusses the physical effet of the Marangoni convection followed by experimental illustrations in section 4.0. Section 5.0 defines the requirements imposed by the Marangoni convection on a multi-purpose heating apparatus and finally section 6 presents the conclusion of this article.

2.0 MATERIAL PROCESSING ON EARTH AND IN SPACE

Materials processed from a melt exhibit compositional and structural defects which limit the exploitation of their full potential. The origin of these defects is related primarily to gravity-induced convective currents in the melt. In semiconductor compounds, additional problems are introduced from variations in stoichiometry. Progress has been made recently in relating qualitatively, and in some instances quantitatively, the growth parameters to the materials properties of the crystals, and in turn to their electronic properties. Overcoming the presence of gravitational forces in space eliminates or minimizes convective interference and, thus, the quantitative assessment of the key growth parameters controlling the chemical and structural perfection of single crystals becomes possible.

Material processing under normal gravity is impeded by inherent problems such as [2]:

a) Compositional inhomogeneities: There is a continuous change in the solute concentration at the solid/liquid interface since mass transport is controlled not only by diffusion but also by convection; this is the macrosegregation. Furthermore, periodic and/or random variations of microscopic growth rates and corresponding variations of the effective distribution coefficient or of the diffusion boundary layer thickness, due to heat and mass transport by time independent or time dependent convection in the melt produces microsegregation.

b) Contamination from the container: the chemical interaction of melts with containers are enhanced by convective flow.

c) Fundamental quantitative studies of crystal growth are impaired by convective heat and mass transport making difficult a quantitative assessment of crystal growth parameters.

d) The accurate determination of impurity distribution coeffficients, diffusivities in the melt, viscosities etc., is intefered with by convective flow.

The microgravitational environment changes the importance between gravitational forces and the other forces involved, but does not necessarily change the relative importance among other forces. The relative reduction of gravitational forces have important consequences during the crystal growth, such as:

a) Surface and contact line phenomena (liquid/solid interface) can acquire greater importance since surface tension is a dominating force. Substantially, higher floating zones, wider minisci, hanging and leaning drops or bubbles and so on can be achieved.

b) Natural convection can be greatly reduced (in fluids) in many configurations that imply gradients of temperature or concentration. This can lead to the formation or unusual extension of concentration boundary layers. Flow driven by interfacial tension may become more prominent and new flow pattern be established (e.g. Marangoni effect).

c) The possibility to achieve a more homogeneous single-phase system.

d) Possibilities for containerless positioning are enhanced (electromagnetic containerless undercooling) since it can be achieved with compensating forces of relatively low intensity. This reduces the disturbances by side-effects such as inhomogeneous heating, vibrations, generation of convection, deformation and splitting of the sample. The elimination of contact helps to avoid undesirable effects that container's walls may have such as chemical contamination or heterogeneous nucleation.

e) Microgravitational environment offers a chance for gaining deeper knowledge on a number of phenomena due to forces of second-order effect (negligible on earth and cannot be studied) compared to the g-forces. Material properties and transport mechanisms can be better and more efficiently studies.

One generally agrees that diffusion and convection are the two dominant mass and heat transfer modes in the liquid in front of the interface. Thus the disappearance of convection will result in a decrease in the driving forces, and also, in a greater regularity of the mass and heat flows. On the other hand, it is well known that mass flows engendered by convection do affect the whole bulk of the liquid, and to a lesser extent the viscous boundary layer that may be reduced in some degree. In a first approximation, if the decay distance of the exponential concentration gradient is less than the viscous boundary layer, there is no effect of convection. On the contrary, in most cases, the process of solute rejection will be affected by convection together with all the phenomena governed by diffusion: redistribution of the solute, efficiency of the heat transfers, instability limits of the interfaces, or size of the solidification structures. The more rapid the rate of solidification, the smaller is the diffusion length.

Furthermore, free convection can generate disturbances of the heat and mass fluxes that may be difficult to control, and may be responsible for pinpoint creation of structural defects in the interface, and later on, in the solid bulk. Convection may be responsible also for temperature fluctuations that may be regulars, oscillatory or even turbulent depending on the value of the Rayleigh number (turbulence - $R > 1800$). When these temperature fluctuations reach the solid/liquid interface, they may induce non-steady state interface motion. For instance, for oscillatory fluctuations, the interface would periodically decelerate or melt back before moving forward again. At first sight, the absence of such fluctuations at the interface would therefore be favourable for the most regular growth of a stable interface and thus, for the improvement in the structural perfection of the resulting solid (crystal). Nevertheless, as there are interfacial instabilities resulting from the liquid phase hydrodynamics instabilities, and, on the other hand, others that are intrinsic, these instabilities together with their cross-coupling will have an effect on the stability of the interface, and subsequently on the perfection of the resulting solid phase. Some of the problems of crystal growth in space are the following:

a) Surface tension-driven convection: a convective flow due to surface tension gradients (Marangoni convection) is produced by thermal and/or compositional gradients. This convection is not a negligible effect and can sometimes dominate the other transport mechanisms. It is also important to realize that, as long as there are free surfaces, Marangoni convection will be present.

b) Surface wetting: good contact is required between the melt and the solid crystal which can be prevented by surface tension.

c) Power and space limitations: single crystals of large dimensions (i.e. approaching those presently in commercial use) are not likely to be grown in the near future due to power and physical space limitations in the actual and future vehicles.

The following sections will examine the effect of the Marangoni convection on crystal growth in a microgravitational environment. Firstly, a description of the physical effect will be presented. The next sections will present some experimental evidence of the Marangoni convection. The last section will examine the implications of this effect on the design of a multipurpose heating facility.

3.0 MARANGONI CONVECTION

In microgravity, the forces due to surface tension become dominant. They belong to two types. The first act at right angle to the phase interface (liquid/gas) and depends on the mean radius of curvature. Under hydrostatic conditions, it balances the Archimedean forces on the fluid volumes partially bounded by the interface. Its increased relevance in the microgravity environment allows the containment of greater volumes. The second type of force due to surface tension acts tangentially to the interface and is due to surface tension gradients (associated with the gradients of surface state parameters such as temperature, composition, and so on) and may be referred to as Marangoni force. Its presence induces motion in the adjoining bulk phase (so called surface-driven or Marangoni flow) as shown in Figure 1 [4].

Figure 1a and 1b demonstrate two indirect effects of gravity: thermal and solutal convective currents. Generally, the density of a fluid decreases with increasing temperature. Therefore, the pressure in the fluid at the bottom of the container is different at both ends. The result is a convective current in the indicated direction. A density gradient can also be caused by a concentration gradient of a solution; the direction of the convective current depends, then, on the type of the solute. Figure 1c and 1d demonstrate the two equivalent effect on the surface. Surface tension may depend upon temperature or concentration. These gradients are either intentionally or accidentally part of many materials science melting processes, thus rising the Marangoni convection to one of the various flow mechanisms which are important for heat and mass transport. This is especially true for melting and melt-crystal growth under the absence of natural convection in a microgravitational environment.

Marangoni convection is caused by gradients of surface tension, σ, due to temperature, concentrations or electric fields gradients at the interface. The Marangoni force which drives the interface fluid particles in the direction of increasing surface tension, is balanced by the viscous shear stresses of the interfacing fluids, and they, in turn, induce motion in the bulk of the fluids [3]. Whenever there is an imposed difference of a parameter affecting the density of the fluids and the surface tension, both buoyancy and Marangoni forces are, in principle, present, but they may be of different orders of magnitude. On earth, the main driving force is usually the buoyancy force, whereas in microgravity the main driving force is the Marangoni force when free surfaces exist. However, there may be situations, both on earth and in reduced gravity environments, in which Marangoni and buoyancy forces are of the same order of magnitude [3].

Marangoni convection involves rather complex mechanisms which are not all well understood. Velocity, temperature and concentration fields in the bulk of the interfacing fluids are strongly coupled through the transport (convective and diffusive) of mass, momentum and energy in both volume and surface phases. Whereas the equivalent coupling due to buoyancy forces is volume-distributed and fades out with diminishing gravity, coupling due to Marangoni forces is concentrated on the interface, depends strongly on its dynamics and thermodynamics and increases at low g levels because larger stable interfaces are attained under these conditions. Bulk phases are often bound by both interfaces and solid surfaces, and this introduces the intricacies of dynamics and thermodynamics of contact lines and contact angles [3]. Figure 2 illustrates a flow pattern that can be produced by the Marangoni convection [13].

The conditions for which Marangoni convection will be present depend on the properties of the liquid, on geometrical factors and on the driving gradient (e.g. temperature or concentration). When a disturbance appears on the surface, two major mechanisms act to reach a new equilibrium state. In the case of a temperature gradient, they are:

a) The convective heat transfer will try to macroscopically move the particles from areas of hotter surface tension to colder; this will produce movement in the bulk because of the viscosity.

b) The thermal diffusion will try to equalize the difference in density with its surrounding by a microscopic exchange of particles.

The ratio of the characteristic time for heat convection by the Marangoni convection and of the characteristic time for heat conduction gives a dimensionless number called the Marangoni number [18]:

$$M = \frac{\alpha \, \Delta T \, L}{\eta \, \xi}$$

where:

- $\alpha = -\partial\sigma/\partial T$ is the temperature coefficient of surface tension,
- ξ is the thermal diffusivity,
- η is the dynamic viscosity,
- ΔT is the characteristic temperature difference,
- L is the characteristic length on the free surface for which there is a temperature difference ΔT; it is the geometrical factor defined by the experimental set-up.

In the case of concentration gradient, the Marangoni number takes a similar form which is:

$$M = \frac{\alpha \, \Delta c \, L}{\eta \, \xi}$$

where:

- $\alpha = -\partial\sigma/\partial c$ is the concentration coefficient of surface tension,
- ξ is the concentration diffusivity,
- η is the dynamic viscosity,
- Δc is the characteristic concentration difference,

- L is the characteristic length on the free surface for which there is a concentration difference Δc; it is the geometrical factor defined by the experimental set-up.

In the limit M->0, the temperature distribution on the free surface will be linear and decreases from the hotter to the colder wall. With increasing Marangoni number, the linear distribution is distorted by the Marangoni convection and develops from the linear into a 'S'-curved shape as shown in Figure 3b of reference [9]. In this figure the dimensionless coordinate s/S of the vertical axis is the position, along the free surface, relative to the total length S, and the horizontal axis is the dimensionless temperature ratio $(T - T_2)/(T_1 - T_2)$. The different curves correspond to different Marangoni numbers; the larger is M the more pronounced will be the S-shape.

When M is low, a steady convection of a single toroidal vortex system is achieved and is considered as the basic steady laminar convection.

As M is increasing, the temperature drop is more and more restricted to the vicinity of the walls and there will even be a number for which the temperature will not change in the middle. As a consequence of the reduction in the temperature gradient, the velocity on the middle part of the free surface decreases, and this will lead to the appearence of two vortices instead of one.

According to the nature of the thermal Marangoni convection, a temperature disturbance on the free surface will produce an instability on the steady laminar convection [8]. A temperature disturbance of the free surface leads to a disturbance of the temperature gradient and to the corresponding disturbance of the surface tension gradient. This latter disturbance induces a distortion of the velocity field which, in turn, will generally cause a distortion of the temperature field in the liquid (bulk and surface). By this coupling mechanism between the surface tension gradient and the heat transfer, a small temperature disturbance could grow or be damped, depending on the ratio of times for heat transfers by conduction and convection; this ratio is the Marangoni number as presented above.

The damping or growing of the perturbation can occur in an aperiodical or oscillatory mode. In the case of the aperiodical growing, the instability evolves into a new steady motion whereas in the case of the oscillatory growing, the instability results in an oscillatory convection. A transition from a single to double or multiple vortex system, as described previously, corresponds to the aperiodical instability.

For the transition into the oscillatory state, the temperature on the free surface will be over-compensated by the convective heat flux; this transition occur above a critical Marangoni number. The temperature distribution on the free surface then begins to oscillate, as do the temperature gradients. It results in the oscillating surface tension and consequently leads to the oscillatory flow with the oscillating vortices and branching lines.

4.0 EXPERIMENTAL EVIDENCES OF MARANGONI CONVECTION

Many experiments were carried out in order to study the mechanism of the Marangoni convection both under 1-g and near 0-g environment [3,6-17] illustrating the phenomenon and evaluating its relative strength relative to buoyant convection.

Schwabe et al [13] have experimentally studied the Marangoni convection with an oxide melt in open boat and Czochralski growth model experiments. They have shown that Marangoni convection cannot be considered a negligible skin effect and that, sometimes, temperature gradients along the free surface are large enough for this type of convection to dominate the buoyant convection even in a 1-g environment. Table 1 presents typical flow velocities of Marangoni and buoyant convection for different compounds for a specific experimental set-up. The experimental conditions were similar for both mechanisms (volume of 1 cm^3, surface of 1 cm and $\Delta T=10K$). As can be seen from this table, the Marangoni convection is the fastest and therefore a very important transport process. Figure 2 illustrates the flow pattern that they have obtained in their experiments. These experiments have also shown that the flow velocity on the surface is a lot faster (about 4 times) than in the bulk of the fluid.

Since on the earth Marangoni convection is difficult to investigate experimentally because it is masked by gravity-induced convection, experiments were also made to study the Marangoni convection under a microgravitational environment [3,7,14] like in the Spacelab I experiment 1ES328; they showed the importance of this mechanism.

Studies on the transition from the laminar state into the oscillatory state have also been performed both on earth and in space [8,9,14] and they concluded that this transition occurs above a certain Marangoni number M^c. Chun et al [9] are presenting the results of an experiment on the transition from a laminar flow to an oscillatory flow and back to a laminar one. It shows the onset of oscillations growing from small spikes into well established rapidly oscillating pattern.

5.0 DESIGN OF A MULTIPURPOSE HEATING APPARATUS

Since, in a microgravitational environment, convection can still play a significant role in the transport mechanisms, one has to try to minimize its influence. Marangoni convection depends on three major factors which are:

- Properties of the fluid: e.g. viscosity, diffusivity, surface tension.
- Driving gradient of surface tension: e.g. temperature, concentration.
- Geometrical factors: e.g. size of the free surface.

5.1 PROPERTIES OF THE FLUID

The properties of the fluid will influence the magnitude of the Marangoni convection as can be seen from the equation of the Marangoni number. The relevant parameters are the temperature coefficient of surface tension (α), the thermal diffusivity (ξ) and the dynamic viscosity (η). Table 2 presents typical values for these parameters for different types of compounds along with the critical product $(\Delta T\ L)^c$ for which the Marangoni number is equal to M^c [12] and above which the Marangoni convection gets into an oscillatory mode.

This Table provides information on the stability and magnitude of the Marangoni convection when one tries to grow specific materials.

5.2 DRIVING GRADIENT OF SURFACE TENSION

The second factor implies that the temperature profile along the free surfaces has to be as flat as possible ($\mathrm{grad}(T) \cong 0$) and as stable as possible ($\partial T/\partial t \cong 0$). This will not only prevent the convection to enter the oscillatory state but also limit the influence of the laminar flow to a minimum.

It is the responsibility of the heating system to provide an adequate temperature profile. In order to obtain a profile with no gradient, resistive heating seems to offer the best promises. The reason for this resides in the fact that, with resistive heating, it is possible to obtain the required length for the required flat zone. Since mirror heating facilities are focusing the light onto a small area, in order to produce a temperature high enough, they do not offer a flat region rendering them inefficient for this purpose.

5.3 GEOMETRICAL FACTORS

The third factor implies that free surfaces should be avoided as much as possible. For space experiment, this is not as trivial as it may seem. An important feature of melt crystallization lies in the fact that the surface tension which forces liquid volumes to take the most advantageous spherical form are dominating. If the melt is being placed in a cylindrical ampoule, it is deprived of an opportunity to be transformed into this thermodynamically most stable state unless it seperates itself from the wall. This means that, in a microgravitational environment, free surfaces can appear between the melt and the ampoule wall. The appearance of these surfaces will enhance the importance of the Marangoni convection.

Since a multipurpose heating apparatus will be used for many different experiments, we can divide its design into two parts which are the heating system and the cartridge where the crystal growth will take place; the latter should be designed to prevent these free surfaces.

6.0 CONCLUSION

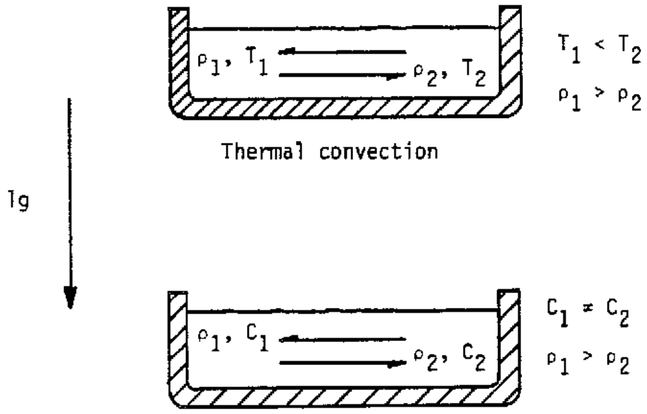
During material processing (solidification, crystal growth...), a microgravitational environment reduces greatly the gravity-induced convection. However, with the reduction of the gravity vector, surface tension becomes a dominant factor in a fluid thus amplifying surface tension effect such as the Marangoni convection.

Marangoni convection, always present when free surfaces exist, can be characterized by a dimensionless number called the Marangoni number M.

The Marangoni number depends on the properties of the fluid (thermal diffusivity, dynamic viscosity and temperature coefficient of surface tension), on the driving gradient of surface tension and on geometrical factors such as the size of the free surfaces. If the Marangoni number is smaller than a critical value M^c, the convection will be laminar whereas if larger, it will be oscillatory.

The design of a multipurpose heating apparatus should take into consideration the possible importance of this effect. Three aspects are important: the experimental set-up should carefully be designed in order to limit the appearance of free surfaces, the heating system should be designed to obtain a temperature profile as flat as possible along the remaining free surfaces and finally knowledge of the fluid properties relevant to the Marangoni convection is important in order to evaluate the magnitude of the effect.

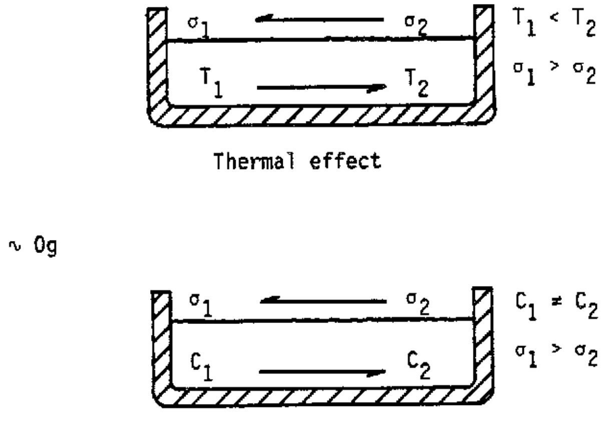
CONVECTIVE FLOW



Thermal convection

Solutal convection

MARANGONI FLOW



Thermal effect

Solutal effect

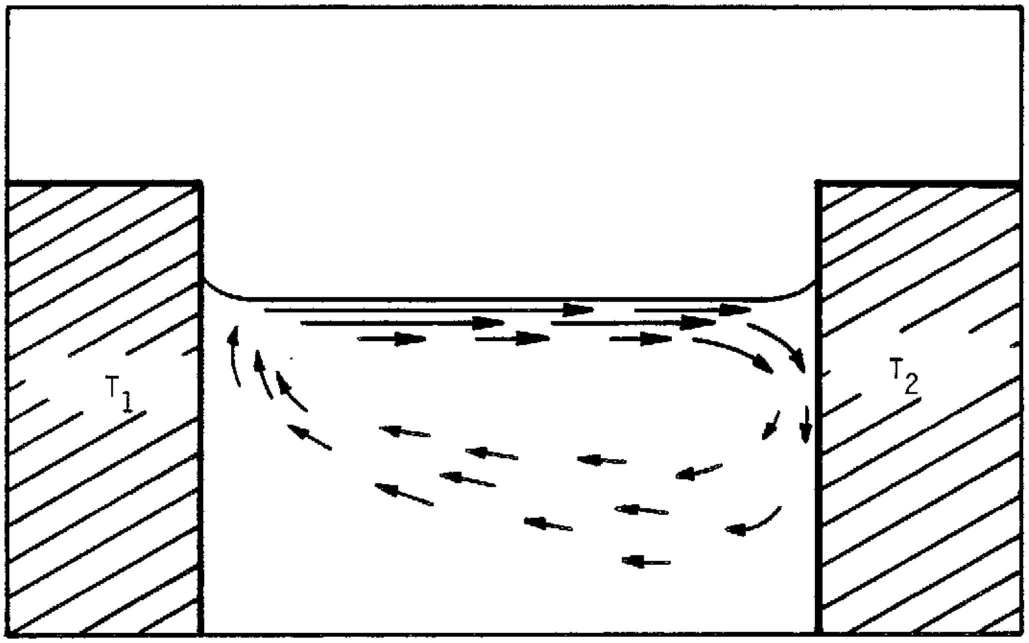

T_1
T_2

Figure 2: Streamlines of Marangoni convection [13].

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Table 1: Typical velocities of convection [13]

Mechanism	Velocity (cm/s)		
	$NaNO_3$	H_2O	Si
Marangoni	2	7	9
Buoyant	10^{-2}	10^{-2}	$5x10^{-3}$

Table 2: Marangoni number (relevant parameters)

Parameter	Unit	$NaNO_3$	Mo	Ga*
α	$(dyn\ cm^{-1}\ K^{-1})$	-0.07	-0.3	-0.1
η	$(gr\ cm^{-1}\ s^{-1})$	0.028	0.02	0.019
ξ	$(cm^2\ s^{-1})$	0.0016	0.1	0.125
$\alpha/(\eta\ \xi)$	$(K^{-1}\ cm^{-1})$	1590	150	33
$(\Delta T\ L)^c$	(K cm)	10	30	63
M^c		16000	4500	2000

* This corresponds to the epitaxial melt growth of GaAs since this is done from a solution of As in liquid gallium.

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MICROGRAVITY PROCESSING OF GLASSES AND CERAMICS

by

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MICROGRAVITY PROCESSING OF GLASSES AND CERAMICS*

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Abstract

The paper describes the processing of glasses and ceramics in the microgravity of space. The advantages of microgravity are identified together with the need for such experiments. The paper also provides a background of theoretical aspects for such investigations.

1. INTRODUCTION:

The exploitation of space for processing of materials (MPS) is one of the new areas of investigation and there is a potential for large stable markets of high value, low mass-items and materials. Typical applications include new ultrahigh temperature materials (glasses and ceramics), fusion target microballons, semiconductors and pharmaceutical processing. MPS is a unique exploitation of space because it may provide products that are not available on earth and may initially be free from competition.

Materials processing in space (MPS) originated in the late 1960's from a consideration of potentially novel behaviour of materials in a microgravity environment. Since then many countries have become actively involved in the exploitation of space for MPS.

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The basic thrust of the United States (US) MPS program is directed to eventual utilization of the effects of microgravity environment for the commercial manufacture of novel products. As a result, the US-MPS program has been directed toward research which may ultimately lead to the development of new materials and processes in commercial applications adding to the nation's technological base. The long term goal being to provide opportunities for independently funded users to exploit the space environment for materials processing applications related to their own needs.

In contrast, the philosphy of the European Space Agency is that MPS research be aimed at scientific advancement rather than immediate applications. To date Japan's effort in MPS has been relatively modest. However, the Japanese MPS program is rapidly gaining momentum and soon will be a major force.

The other major investigator in MPS is the U.S.S.R., where a broad range of studies in materials science in space has been undertaken. Recent estimates of the U.S.S.R.'s program funding indicated that the amount involved was at least three to four times larger than that of NASA.

Materials Processing in low-gravity environment eliminates the undesirable effects of sedimentation, buoyancy, hydrostatic pressure and convection on the quality of processed products such as glasses, ceramics, metals, fluids and cells. This will result in unique, higher-quality products and purer substances. Among the promising areas of space-based materials processing are furnace processing of ultrahigh-temperature glasses and immiscible alloys.

In the past decade the lack of adequate materials having required properties has increasingly become the limiting factor in the development of complex hardware. An example of this is the materials limitation imposed on magneto-hydrodynamic power generation by the lack of suitable high-temperature electrodes and insulators. Other examples in the fields of medicine, communications, and space travel could be cited where knowledge to achieve certain objectives exists, but no existing materials are capable of performing the desired function. In many applications ceramics are the only candidate materials considered likely to perform the required function.

Such "materials limitions" provide an important impetus for investigating the processing of glasses, ceramics and composites in the unique outer-space enviroment. Some applications that are currently being looked at include laser glasses, laser windows and IR fibre optics, unique optical glasses for multi-element lenses and magneto-optical devices.

The advantages of microgravity processing of glasses and ceramics can be summarized as follows:

- processing materials for in-space use. Examples are building components such as insulating foam and fibre blocks
- processing of materials which cannot be obtained on earth. Examples are new host glasses for high power lasers
- development of improved processes and materials for future terrestrial production. Examples are defect free crystals etc

2. GLASSES AND CERAMICS:

Glasses and crystalline ceramics are a group of inorganic non-metallic materials that are usually processed at elevated temperatures. These materials range from high technology products, such as solid-state electronic components and high-strength fibres to more traditional products such as window glass, bricks and tableware. The value of US production of manufactured ceramic products currently exceeds 10 billion dollars annually. But perhaps, even more important than their monetary value, the materials are also critical to many other technologies. For example, ferrite ceramics as memory cores are essential to high speed computers.

3. MICROGRAVITY PROCESSING OF GLASSES - A CASE STUDY:

Space processing has the potential to make an important new area of optical glasses a reality. The problem is illustrated schematically in Figure.1, which shows the range of commercially available glasses today. Attempts to prepare low dispersion glasses (higher Abbe numbers) have not been successful because of the processing problems related to complex compositions.

Glasses can be prepared under microgravity from otherwise reluctant glass forming oxides, processed into useful shapes without phase separation problems and thus the range of glasses with useful properties can be expanded significantly.

4. CRITICAL COOLING RATES AND GLASS FORMATION:

When a molten oxide is cooled slowly to approach equilibrium conditions, it crystallizes. The crystallization phenomena may be considered to occur in two stages: 1. Nucleation and 2. Crystal growth. In the case of conventional glasses, the viscosity of molten glass is very high resulting in low molecular mobility. This in turn effectively inhibits both nucleation and crystal growth, especially the crystal growth. Even if the material manages to nucleate, on cooling from the melt, the crystal growth rate is so slow that the nuclei remain for all practical purposes undetectable in glass.

In the field of speciality optics, glasses have been prepared from some of the less viscous oxides. High cooling rates are required to produce these glasses and techniques such as splat cooling have resulted in samples of limited practical use. Some compositions could not be prepared in the form of glasses either due to critical cooling rates required or due to phase separation problems on reheating. Microgravity processing offers the first opportunity to prepare such glasses for a number of practical applications. The importance of critical cooling rate in homogeneous and heterogeneous nucleations is shown schematically in Figure-2. Table-1 lists a number of possible glass systems that can be prepared in space.

Microgravity processing will provide important information on two broad fronts and is summarized below:

- o Phenomenalogical Properties:
  - nucleation and crystallization
  - immiscibility
  - bubble motion
  - weak forces; diffusion, surface and interfacial tension
- o Processing Technology:
  - homogen ization
  - high purity material processing
  - high temperature processing
  - shaping

5. MARKET CONSIDERATIONS:

Cost is a major factor in determining the feasibility of commercial space manufacturing of glasses and ceramics. To be competitive with similar earth-manufactured products, the space product must be either lower in cost or there must be substantial improvement in product value that ensures the sale of the product at a higher price than that of earth products. Considering the example of laser glasses, a factor of 5 to 10 improvement should ensure that the space product can compete with the earth product. The probability of producing such glasses in space has a 75% probability and with the average high power laser system ranging around $150,000 the space product with its inherent quality should have no difficulty in competing with the earth based products.

REFERENCES

Space Station Industry Joint Endeavour Programme: Microgravity processing of Glasses, Ceramics and Composites. Report prepared for the National Research Council under Contract OSR84-00149, April 1985.

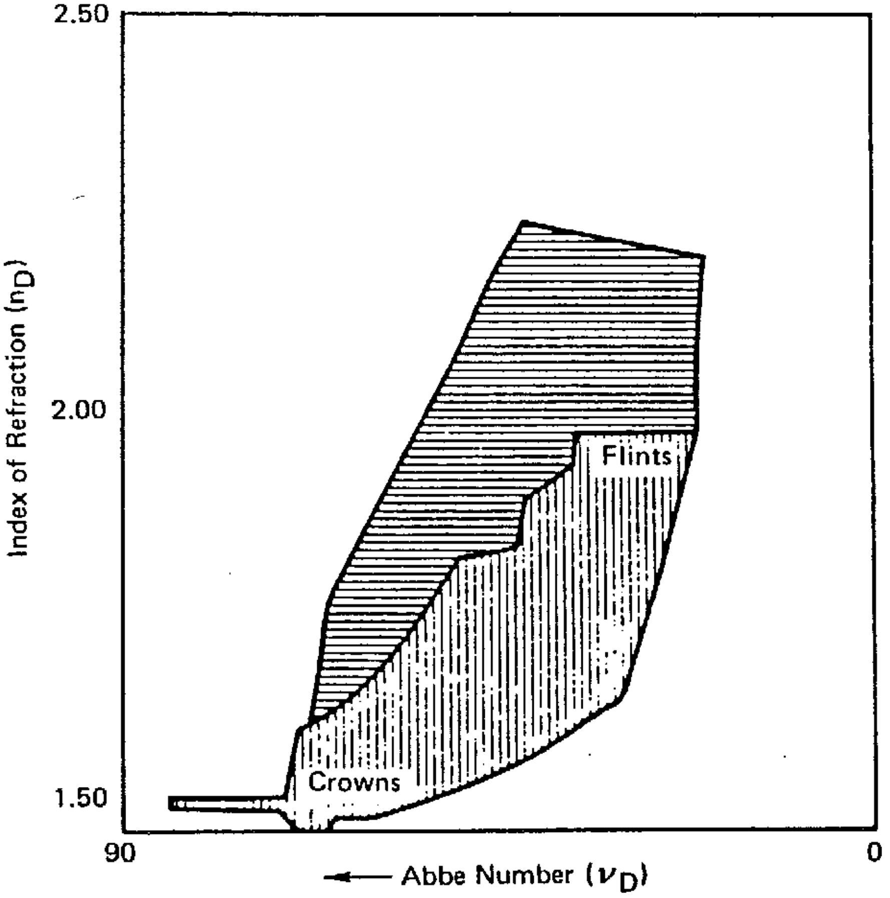
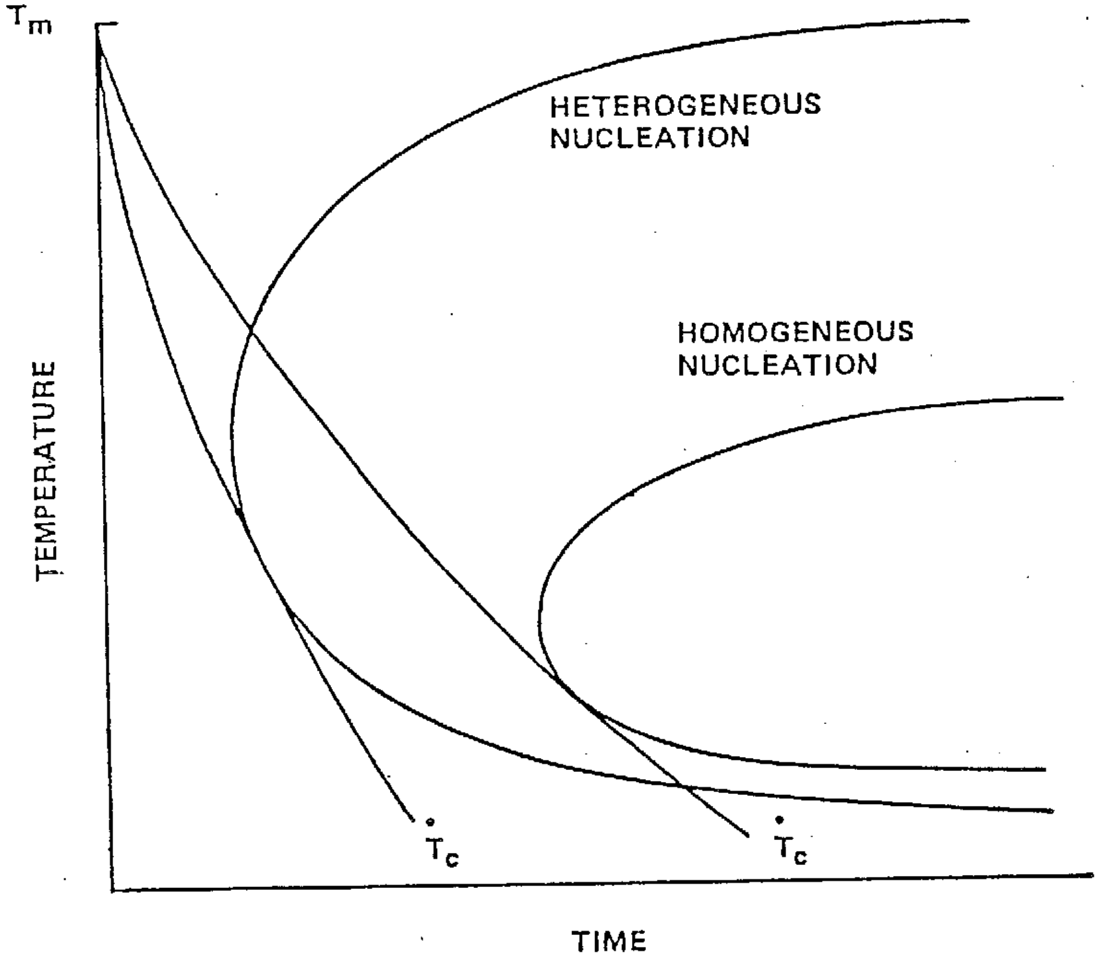


Figure 1. n-ν Diagram for Optical Glasses

Figure-2



HYPOTHETICAL TIME-TEMPERATURE-TRANSFORMATION (TTT) DIAGRAM FOR A SYSTEM FOR BOTH HETEROGENEOUS AND HOMOGENEOUS NUCLEATION. THE CRITICAL COOLING RATE, T_C, TO FORM GLASSES WHEN HETEROGENEOUS NUCLEATION IS PRESENT IS MUCH LARGER THAN WITH ONLY HOMOGENEOUS NUCLEATION.

Table-1

Potential Glass materials for Space Processing

Material	Melting temp. T_m °C	Processsing temp. T_{max} °C	Glass transition temp. T_g °C
HfO_2	2,897	-	-
ZrO_2	2,675	-	-
Y_2O_3	2,410	2,600	1,520
Al_2O_3 + 20w/o SiO_2	2,050	2,250	1,190
CaO + 40w/o SiO_2 + 0.5w/o Nd_2O_3	1,480	1,700	950
65w/o ZrF_4 + 35w/o BaF_2	850	1,000	570
60w/o ZrF_4 + 35w/o BaF_2 + 5w/o LaF_3	810	950	590

THE CANADA CENTRE FOR SPACE SCIENCE

by

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CANADA CENTRE FOR SPACE SCIENCE

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Introduction

This paper briefly reviews the activities of the Canada Centre for Space Science (CCSS) and outlines the role which CCSS can play in support of Materials Processing in Space.

CCSS Purpose and Organization

CCSS is a division of the National Research Council of Canada which provides major facilities and a significant fraction of the funding for the Canadian space science programs. Unlike similar organizations in some other countries, the mandate of CCSS is limited to the provision of facilities. CCSS does not fund the salaries or other expenses of scientists who are involved in the development and use the facilities. CCSS contracts with Canadian industry for the development of facilities, has no "in-house" laboratories, and serves a scientific community which is external to CCSS.

CCSS supports the development of both dedicated and multi-user space-borne facilities and associated ground-based equipment. At the present time, two instruments are under development for flight on the Shuttle/Spacelab system, three instruments for free-flying satellites are in progress, and a network of ground-based magnetometers, riometers, photometers, and imagers is being implemented. In the area of Materials Processing in Space, two experiments to be flown on a Swedish sounding rocket and a number of experiments to be accommodated on the shuttle in a "Hitchhiker" payload of opportunity carrier are presently being supported by CCSS. These programs are described elsewhere in these proceedings.

In a typical project scenario, a Principal Investigator and a team of scientific co-investigators is established which has responsibility for defining the scientific performance requirement of an instrument or system. CCSS, through in-house engineering studies or by contract with industry, produces engineering specifications and mission plans which are then used as the basis for contracts with industry to develop the required instrument or facility. The science team monitors the development activity, plans and participates in or directs mission operations, and is responsible for scientific data analysis.

Project Selection Processes

CCSS is at present supporting activities in four areas of space science -

- space plasma physics
- upper atmosphere chemistry and physics
- microgravity research (e.g. materials processing in space)
- space astronomy

The order of the above list does not reflect any priorities but is indicative of the present program emphasis.

Proposals for specific projects usually originate in the scientific community rather than in CCSS. In general, proposals pertain to either "international collaborative" projects or independent initiatives. The possibilities of projects in the first category usually arise at irregular intervals due to opportunities to participate in a foreign program. The opportunity may be presented formally as in the case of a NASA "Announcement of Opportunity" or may arise informally through contacts with foreign scientists or agencies by Canadian scientists or CCSS. Proposals to respond to such opportunities are reviewed by CCSS from scientific, technical, management, schedule, and budgetary perspectives and the degree of scientific interest in Canada in the proposed activity is determined. If the proposed project is feasible, has good scientific merits, is of broad interest, and can be accommodated within the uncommitted portion of the CCSS base budget, the project is approved. The number of opportunities for such projects in general significantly exceed financial resources to support them. Due to the irregular timing of the generation of such proposals and the short response time typically required, it is usually not possible to consider proposals in this category in competition with each other.

Potential projects which are largely independent Canadian initiatives are treated differently. In this case, calls for experiment proposals are usually issued to Canadian scientists by CCSS and proposals received are subjected to scientific peer review processes and evaluation from standpoints of technical feasibility and cost. Proposals are rank ordered and as many approved as the available budget will permit. It is expected that a call for proposals for microgravity science experiments which could be accommodated by a NASA "Hitchhiker" carrier flight in late 1987 will be issued shortly. In addition, some limited experiments could be accommodated on a Hitchhiker payload which is under development for launch in late 1986.

CHEMICAL METALLURGICAL PROCESSING IN SPACE

by

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University of Toronto

CHEMICAL METALLURGICAL PROCESSING IN SPACE

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Department of Metallurgy & Materials Science

This symposium comes at a time when there is considerable scientific interest in the potential of microgravity conditions for basic research studies. It would seem inappropriate to look for an economical return from the results of operations in space at the present time, but I take the view that many such experiments could elucidate problems related to metallurgical processing on Earth by eliminating density differences between the reactants which is a complication in the design of experiments.

To the industrialist this may seem to be a feeble reason for committing significant sums from the small research funds which are available nationally to research in microgravity. However, recent experience of a similar nature in plasma metallurgy has taught me that during a decade,an initially uneconomical research field, with technological implications, can be developed to solve problems which have emerged during that time because of new and unexpected circumstances. Furthermore products which could not have appeared of any significance a decade ago can now be obtained, and only obtained, from plasma metallurgical devices.

Encouraged by this experience, I now want to discuss aspects of experimentation in micro-gravity which will broaden our experimental capabilities at the present time, but which may lead to wider industrial application a decade from now.

I will discuss these topics under three headings: systems in uniform and non-uniform temperatures, and other space potentials apart from microgravity alone.

Systems in uniform temperatures

The high temperature scientist who is interested in chemical reaction kinetics and in solution-dissolution processes at high temperatures is very much concerned with separating interface control at reactant surfaces, from diffusion control within reactant volumes. The optimum contact between reactant phases can be achieved when one reactant is in the form of a finely dispersed phase within the other reactant. Unfortunately, such dispersed phases are difficult to achieve when one of the reactants is a liquid because sedimentation of the heavier phase and therefore segregation of the reacting interfaces under gravity rapidly occurs. Such rapid separation of reactants due to density differences would be avaoided in microgravity. Typical experiments which could be effectively carried out in space would be the study of Ostwald ripening of a dispersed solid or liquid phase in a liquid matrix, and the reduction of liquid oxide slags by carbon.

Other experiments where the absence of convection would be valuable to an experimental study are, for example, the mechanism of the "notching" of container crucibles at metal/slag and slag/gas interfaces, and the nucleation kinetics of oxides in liquid alloys into which oxygen atoms can be "pumped" individually and at known rates using solid oxide electrolytes.

Systems in temperature gradients

The effects of gravity during diffusion studies have already been well recognized in systems at uniform temperatures, but in liquid systems further problems arise in a temperature gradient. Thermal diffusion is an important high temperature phenomenon in the study of which convective effects make almost insuperable difficulties. Studies of electrochemical effects which are related to non-isothermal operation such as the Seebeck coefficient, and the entropy contribution to electromotive forces in galvanic cells could be far more readily carried out in microgravity than on Earth.

The important field of vapour phase transport is treated at present under the assumption that local equilibrium exists between the gas phase and source of material at one temperature, and between the gas phase and the sink of material at another temperature. This "thermodynamic" approximation leaves out any irreversible phenomena and thus is incomplete. Those irreversible contributions could best be obtained by experiment under microgravity.

The morphology of dissolution and precipitation of solids via a liquid dissolving phase is important in understanding the redistribution of material that occurs via the liquid when source and sink of the solid are at different temperatures. Experiments of this kind are usually difficult to interpret under terrestrial conditions because of convective transport in the liquid phase.

Other Space facilities

Although the stress in this Symposium is on the advantages of experiment under conditions of microgravity, I believe there are other aspects of operations in space which should be considered.

It is quite probable that mining and metal production will be carried out at a lunar base early in the 21st century, and this will be under conditions of reduced, but finite, gravitational effects when compared with operations on Earth. Clearly we could use the gravitational effect as a variable by operating under centrifuge conditions in microgravity in order to simulate conditions on a lunar base. There might be other, scientific, advantages from studies carried out at intermediate gravitational levels.

The presence of infinite pumping capacity in space suggests that molecular beam studies on beams emitted from high temperature and almost atmospheric (101 Kpa) pressure, could be made with advantage in space. Studies using conventional mass spectrometers with Knudsen sources are limited to total source pressure of about 10^{-4} atmos. Under these conditions many minor species escape detection. Higher pressure operation, which requires very high pumping speeds, requires the use of extremely powerful and very costly vacuum pumps. When sufficiently clean conditions and low pressures can be achieved in space, some important molecular beam studies could be made with much simpler equipment.

Finally, the solar energy source in space suffers far less attenuation and is much more predictable in availability than is the case on Earth. New materials, such as very high melting ceramic solid solutions having valuable electrical properties, could be prepared by fusion using solar energy where the temperature of the solar source, about 3500°C,exceeds the melting points of these materials. Single crystals could be prepared of sufficient size in relatively short times given the uninterrupted availability of solar energy over a few tens of minutes.

Conclusion

It can be seen from these brief notes that research in space offers a number of new and valuable experimental advantages to the high temperature chemist. If a rationale were required for the investment of funds in such research in the near future, I would suggest that the winning of basic information which augments our capability of analysing more completely our operations on Earth, and the awakening of scientific imagination to new possibilities of resolving current materials problems would be a sufficient catalyst to inspire some effort in this field.

SYSTEMS AT UNIFORM TEMPERATURES

1. Interfacial vs. Diffusion control in dispersed phase systems

    A. Establishment of Ostwald ripening phenomena for liquid-liquid, liquid-solid systems with no chemical reaction.

    B. Kinetics of interphase reactions with significant density difference between phases e.g. carbon-vanadium-rich slags.

2. Elimination of convection effects

    A. Liquid-solid corrosion reactions e.g. ceramic-slag corrosion, "slag-notching" at metal-slag interface.

    B. Electrochemical pumping of atomic species to study early stages of second-phase nucleation e.g. oxygen into nickel-yttrium.

SYSTEMS IN TEMPERATURE GRADIENTS

A. Direct entropy of formation and Seebeck coefficient measurement of molten phases using electrochemical cells

B. Thermal diffusion in liquid and gaseous mixtures

C. Vapour phase transport reactions and the "thermodynamic approximation"

D. Solution-precipitation through a liquid medium to solid planar surfaces

OTHER SPACE FACILITIES

1. Controlled gravitational effects
2. Mass spectrometry with one atmosphere pressure source, for minor species
3. Long-term solar energy source for the preparation of single crystals of very high melting solid electrolytes

PREPARING EXPERIMENTS FOR STS SPACE FLIGHTS

A CASE STUDY

by

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University of Toronto

Introduction

The purpose of this report is to provide prospective experimenters for future STS space flights with a brief overview of the procedures and tasks involved in qualifying payloads. In doing so, the author has made use of the experience gained in preparing a Composite Materials Experiment (including the design and construction of an automated data recording system capable of operating for extended periods aboard a free flying satellite) for inclusion on the NASA Long Duration Exposure Facility (LDEF), launched on April 4/84 and scheduled for retrieval in 1986. The design and space qualification of a non-passive experiment is very costly, particularly in terms of the man-hours required to certify the payload, as will become evident throughout this text. From a university perspective, the funds for such an undertaking have to be found from external sources and can amount to several hundred thousand dollars in total by the time a final report on the experimental findings is published. By way of example, Fig. 1 illustrates the funding agencies who contributed to our LDEF experiment. Both government and industrial interests were present, including extensive in-house funding to cover 'cost-overruns' at various stages of the programme. It can readily be seen that two major benefits from this experiment are anticipated; the actual composite materials' degradation data (which can also be used to compare with simulator results) and the data recorder itself. If this unit functioned satisfactorily throughout the flight, then it represents a potential commercial spin-off that can be sold to other users.

Although this case study is based on our LDEF experiment, it is felt that the procedures and tasks involved in meeting NASA's requirements are common to other payloads. Thus an attempt has been made to generalize the information presented, although reference to LDEF is occasionally made.

Procedures for Qualifying STS Payloads

Figure 2 presents a listing summarizing the various stages one must go through, beginning with the initial proposal requirements (see Fig. 3) and followed by several design and safety reviews. It should be emphasized that except for the actual space flight itself, each phase in Fig. 2 necessitates the preparation of a report involving the experimenter. Essentially the qualification process can be subdivided into two major activities - the design phase and safety review process, each of which is subject to some degree of verification by NASA.

Payload Design

Subject to proposal acceptance, a significant effort is required to prepare an initial design report for submission to NASA. Topics addressed include thermal, mechanical and electrical aspects related to the experiment and how it will meet orbiter and/or free flying satellite conditions (such as LDEF or the proposed EOIM space carrier for example). For example, Fig. 4 presents thermal design environments for the orbiting satellite case, as well as the temperature ranges encountered on the launch pad, during launch (in the payload bay), with and without the doors open and during re-entry. The point that must be emphasized is that the experimenter must demonstrate by a thermal model analysis (which in itself requires estimates or measurements of absorbtivity/emissivity and thermal conductivity to be made) that the hardware and package can meet these requirements.

The other major consideration is that of mechanical loads. Figure 5 summarizes nominal STS g loads during various phases of launch and re-entry. However, these values will generally change for a given payload, depending on its location in the cargo bay and whether or not it is mounted on a satellite for example. In the LDEF programme, the g load requirements were prescribed for a given tray location and it was necessary to demonstrate via a stress analysis that the experiment could withstand the loads with no component failures. Furthermore, the vibration load spectrum shown in Fig. 6 was also applied to the experiment (along all 3 axes of the tray, as indicated by L, M, N in Fig. 5) by NASA prior to flight certification. One is well advised to perform these tests prior to delivery to NASA to ensure that the package not only survives but functions properly (under thermal-vacuum conditions if in the cargo bay or on a satellite). In our case, these tests were done at various sub-structure (or component) levels both at UTIAS and the David Florida Laboratory at DOC/CRC in Ottawa. This prior testing did indeed point out some design flaws in the mechanical fasteners and in a few electrical components in the data recording system.

NASA's safety policy and requirements are summarized for selected areas of concern in Fig. 7. Note that in the stress analysis case, ultimate safety factors of 1.4 were required. Implicit in meeting these conditions is the necessity of assembling a complete list of all materials used to construct the experiment. Material type descriptions and weight (or volume used) are mandatory so NASA can perform an offgassing/outgassing analysis to assess if toxic/contaminant problems exist. If so, the experimenter will often be required to change a material selection.

Safety Assessments

Several NASA organizations are responsible for assessing and certifying that each experiment to be flown on the STS is 'safe'. Figure 8 provides an administrative management flowchart, each component of which deals with safety requirements as outlined in Fig. 9. There are 4 safety reviews conducted, based on information provided by the experimenter as noted earlier. These reviews (see Fig. 10) occur at various stages of development in the experiment acceptance process and each requires extensive documentation. If in fact the experiment faces major difficulties in meeting NASA requirements, there does exist the possibility of seeking a 'waiver' on a specific issue. As can be seen in Fig. 11, considerable documentation and justification would be needed to convince the safety authorities to grant a 'waiver'.

Summary

A brief overview has been presented using the UTIAS-LDEF Composite Materials Experiment as a case study. In an attempt to summarize the extensive reporting requirements necessary to qualify an experiment for STS flight, Fig. 12 has been prepared for the reader's guidance. It should be evident that extensive preparation and design must go into flight qualification of a payload, particularly if it encompasses an 'active' experiment.

University of Toronto
Institute for Aerospace Studies

Composite Materials Experiment on the NASA Long Duration Exposure Facility STS-41C

(Launched April 4/84)

Programme Support

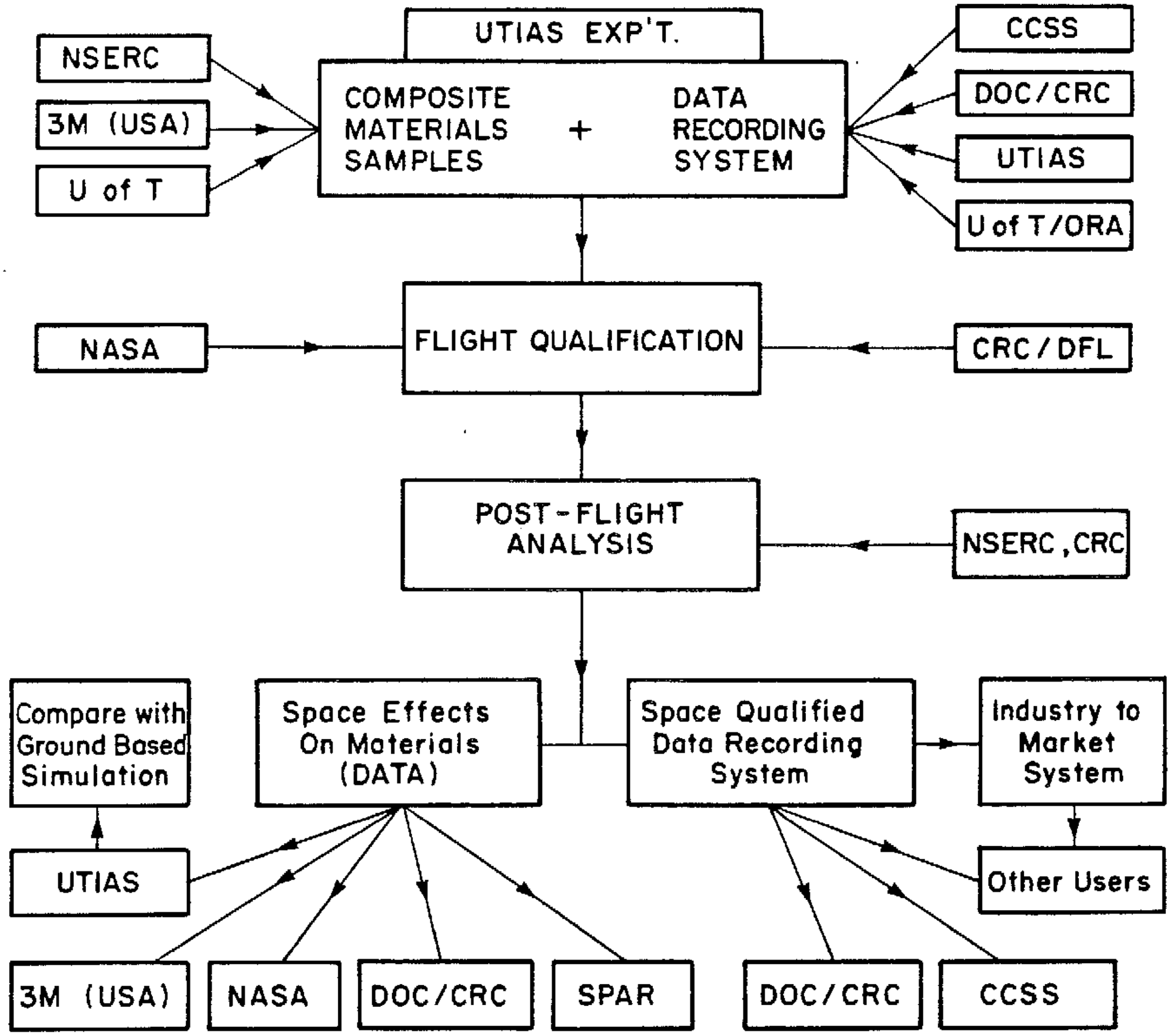


FIG. 1

Procedures for Qualifying and Flying STS Payloads

- Proposal
- Payload Design (Mechanical, Electrical and Thermal)
- Selection
- Preliminary Design Report to NASA
- Design Reviews
- Safety Reviews
  - 1- Concept 2- Prelim. Design 3- Critical Design 4- Delivery
- Construction
- In-house Component Performance Verification Testing (Thermal-Vacuum, Shock Loads and Vibration)
- NASA Qualification Tests
- Payload Integration Operations by NASA at KSC
- Pre-Flight Test Operations and Procedures checkout by Experimenter
- Flight
- Post-Flight Operations, Procedures and Inspection
- Procedures for Payload Delivery to Experimenter
- Data Reduction, Analysis and Report Preparation

- FIG. 2

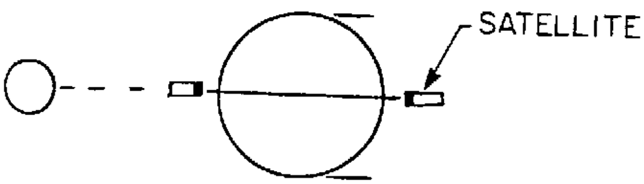
EXPERIMENT PROPOSAL

- size, weight, power requirements
- hardware description
- safety hazards
- ground handling and launch requirements
- deployment / exposure requirements
- manpower, costs, organization

FIG. 3

- TWO CASES:

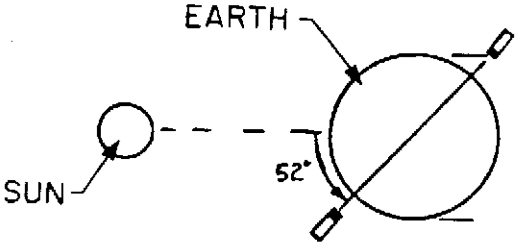
COLD



MAX SHADOW (63% SUN)

MIN PROJECTED AREA
MIN ALBEDO
MIN SOLAR CONSTANT
MIN EARTH TEMP
MIN α/ε COATINGS

HOT



MAX SUN (72% SUN)
28½° LAUNCH INCLINATION
MAX ALBEDO
MAX SOLAR CONSTANT
MAX EARTH TEMP
MAX α/ε DEGRADED COATINGS

- VARIABLES CONSIDERED:

ORBITAL ALTITUDE
COATING CHANGES
TRANSIENTS

LEADING EDGE VARIATION
CONDUCTION
EXPERIMENT PROPERTIES

- LAUNCH PAD

60° - 70° F

- LAUNCH

10°F RISE FROM PRELAUNCH (<100°F)

- ON ORBIT - DOORS CLOSED

10°F TO 120°F BY MISSION CONSTRAINTS
60°F TO 90° F PROBABLE RANGE

- ON ORBIT - DOORS OPEN

10°F TO 120°F AVERAGE
EXPERIMENTS WITHIN FREE FLIGHT EXTREMES
TEMPERATURES ACHIEVED BY FLIGHT OPERATIONAL CONSTRAINTS

- REENTRY

PURGE ACTIVATED 15 MINUTES AFTER LANDING, CONSTRAINT - PAYLOAD & BAY CONDITIONED PRIOR TO REENTRY TO PROVIDE < 120° F. MAXIMUM AVERAGE TEMPERATURE

MAXIMUM WALL TEMPERATURE - 250°F
MAXIMUM GAS TEMPERATURE - 480°F (LOW Q)
ONLY LOW MASS SURFACE EXPERIMENTS WOULD EXPERIENCE HEATING

FIG. 4

		ACCELERATION - G's		
		L	m	N
LAUNCH AND POWERED FLIGHT	LIFT-OFF	±2.90	±1.80	±1.80
	HIGH Q	±2.00	±0.80	±0.80
	MAX BOOST	±3.30	±0.36	±0.36
	SHUTTLE MAX	±3.30	±1.10	±1.10
RE-ENTRY AND LANDING	ENTRY (PITCH)	±1.06	±2.80	±2.80
	ENTRY (YAW)	±0.75	±1.80	±1.80
	LANDING	±1.00	±2.84	±2.84
	EMERGENCY LANDING	±4.50	±4.50	±4.50

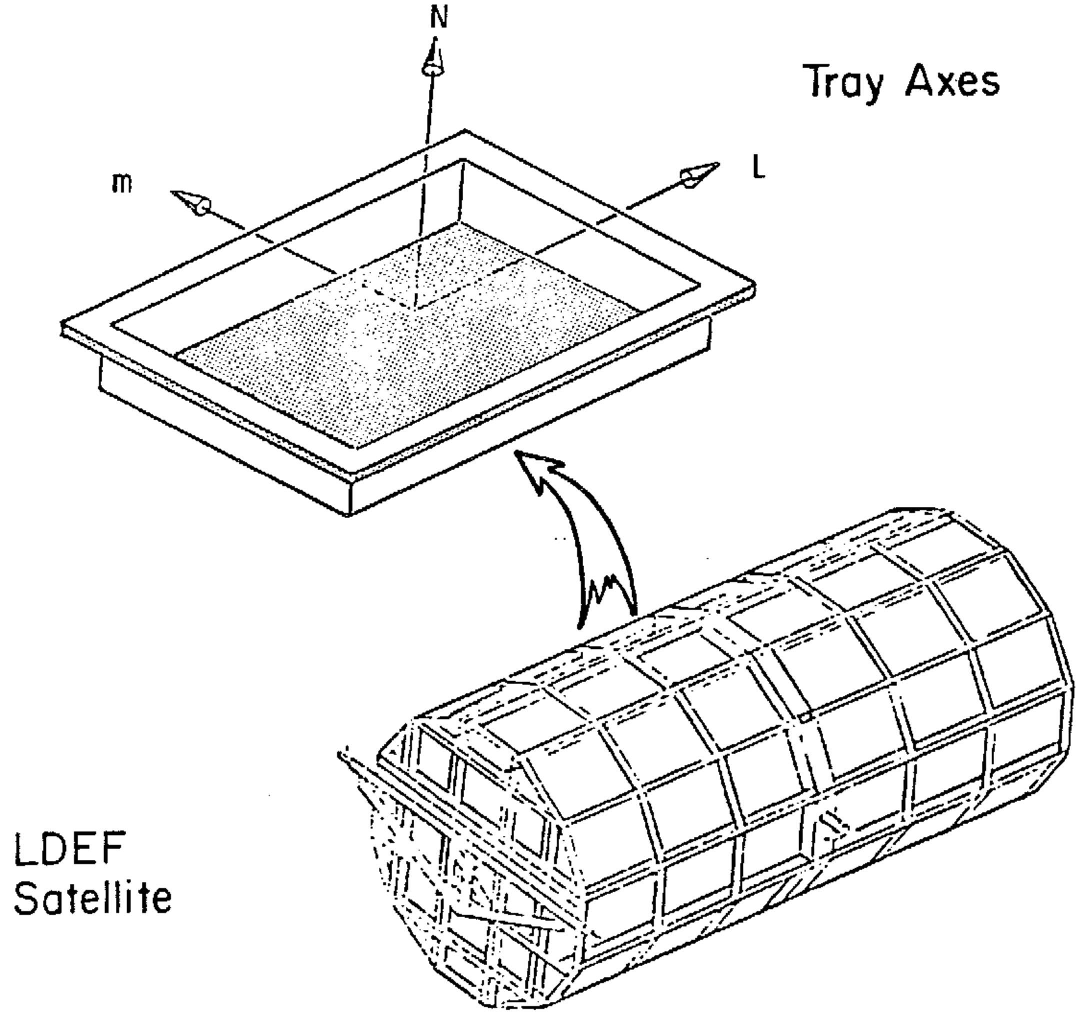


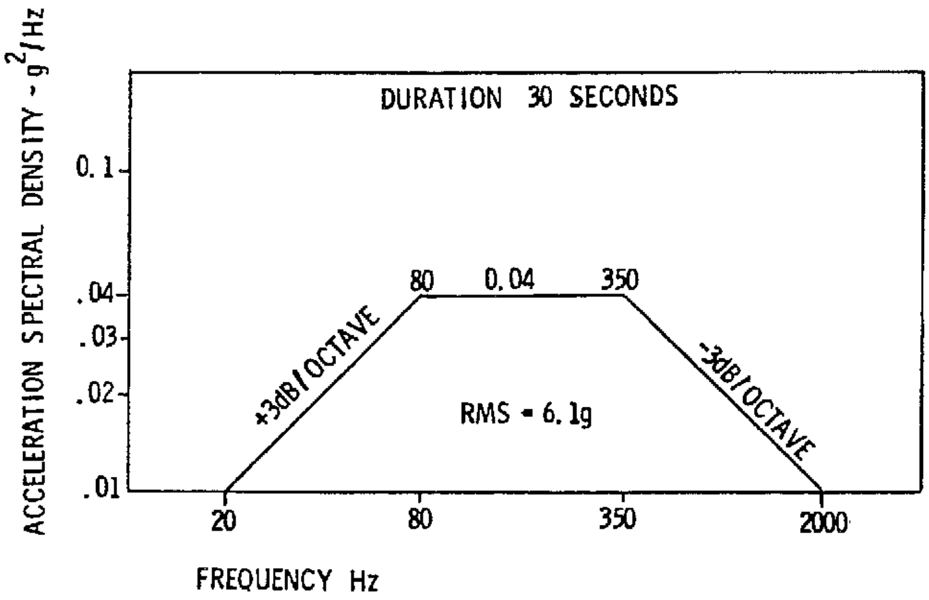
FIG. 5

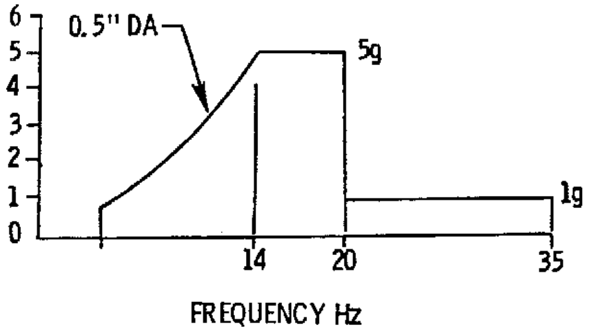
VIBRATION TEST

- RANDOM AND SINE - ALL THREE MUTUALLY PERPENDICULAR AXES

TEST SPECTRUM

- RANDOM
  - APOLLO ACCEPTANCE TEST SPECTRUM FOR ALL EXPERIMENT TRAYS
- SINE
  - TYPICAL SPECTRUM - TEST LEVELS WILL BE DETERMINED BY LOCATION OF EXPERIMENT ON LDEF
  - LDEF/STS COMBINED LOADS ANALYSIS WILL BE REVIEWED FOR LIFTOFF AND LANDING ACCELERATIONS FOR EACH AXIS
  - MAXIMUM PREDICTED ACCELERATION FOR EACH AXIS TIMES A FACTOR OF 1.4 WILL ESTABLISH EXPERIMENT CERTIFICATION TEST LEVELS. SWEEP RATE = 4 OCTAVES/MINUTE





DURATIONS:	5 - 20 Hz	4 OCTAVES/MIN.
	20 - 35 Hz	4 OCTAVES/MIN.

APPLIED ALONG EACH OF THE 3 AXES OF THE TRAY

FIG. 6

SAFETY POLICY & REQUIREMENTS
TECHNICAL REQUIREMENTS
FOR LDEF EXPERIMENTS

STRUCTURAL (208)

STRUCTURAL DESIGN

- ULTIMATE FACTOR SAFETY ≥ 1.4

STRESS CORROSION

- MATERIALS MUST COMPLY WITH MSFC - SPEC - 522
- WAIVER REQUIRED FOR CASES WHEN MSFC - SPEC - 522 REQUIRES MATERIAL USAGE AGREEMENT

PRESSURE VESSELS

- DESIGN TO ASME BOILER AND PRESSURE VESSEL CODE OR MIL-STD-1522 OR NSS/HP 1740.1 WITH F.S. ≥ 1.5
- FLUID COMPATIBILITY FOR CLEANING TEST AND OPERATION

PRESSURIZED LINES AND FITTINGS

- FITTINGS AND LINES < 1.5 INCHES INSIDE DIA. SHALL HAVE FACTOR OF SAFETY ≥ 4.0
- FITTINGS AND LINES > 1.5 INCHES INSIDE DIA. SHALL HAVE FACTOR OF SAFETY ≥ 1.5
- OTHER COMPONENTS SHALL HAVE FACTOR OF SAFETY ≥ 2.5

SEALED CONTAINERS

- ANALYZED TO ESTABLISH HAZARD POTENTIAL
- PROOF TEST 1.5 NOMINAL DIFFERENTIAL IF A HAZARD

MATERIALS (209)

HAZARDOUS MATERIALS

- HAZARDOUS MATERIALS SHALL NOT BE RELEASED OR EJECTED IN OR NEAR ORBITER
- MUST CONTAIN HAZARDOUS FLUIDS AFTER EXPOSURE TO ALL STS ENVIRONMENT UNLESS VENTING NEGOTIATED WITH STS OPERATOR

FLAMMABLE MATERIALS

- OTHER THAN ORBITER CABIN GOOD PRACTICES ARE REQUIRED
  - FLAMMABLE MATERIALS SEPARATED TO PREVENT FLAME PROPAGATION
  - SEPARATE FLAMMABLE MATERIALS FROM IGNITION SOURCES TO MAXIM

FIG. 7

PYROTECHNIC INITIATORS (210)

- ALL PYRO SUBSYSTEMS AND DEVICES SHALL MEET MIL - STD - 1512

NASA STANDARD INITIATORS

- FULLY COMPLY WITH SPECIAL REQUIREMENTS AND REQUIRE NO FURTHER DEMONSTRATION

RADIATION (212)

IONIZING RADIATION

- ALL PAYLOADS THAT CONTAIN, USE, OR GENERATE IONIZING RADIATION SOURCES REQUIRE APPROVAL PRIOR TO USE

NONIONIZING RADIATION

- PAYLOADS SHALL NOT EMIT ELECTROMAGNETIC RADIATION (INCLUDING X-RAYS) WHICH PRESENT A HAZARD
- MAXIMUM ACCEPTABLE CARGO-PRODUCED FIELDS PER VOLUME XIV
- TRANSMITTERS OFF DURING BOOST AND ENTRY

ELECTRICAL SYSTEMS (213)

- DESIGN SO THAT FAULTS DO NOT CREATE IGNITION SOURCES FOR PAYLOAD OR ORBITER MATERIAL

VERIFICATION REQUIREMENTS (214)

- TEST, ANALYSES AND INSPECTION ARE TECHNIQUES

FIG. 7 (CONT'D)

STS PAYLOAD

SAFETY MANAGEMENT

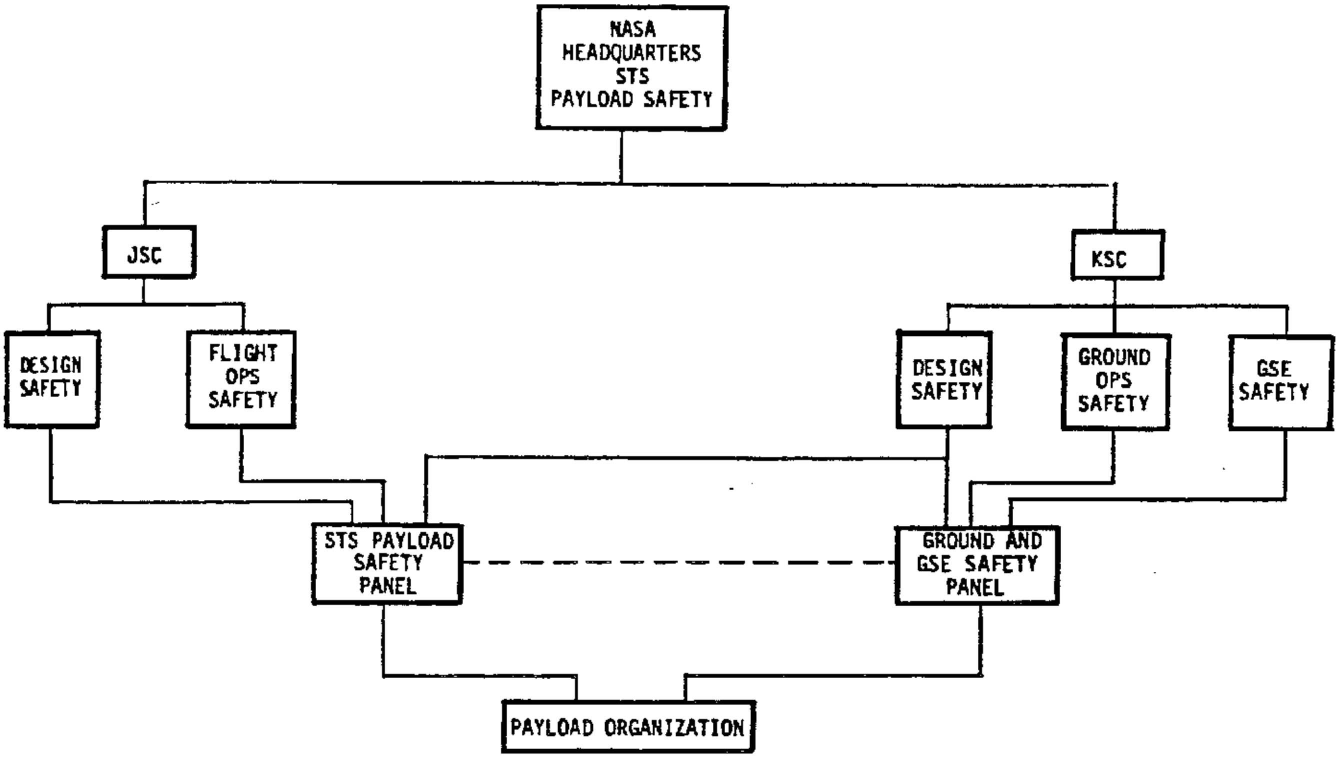


FIG. 8

SAFETY IMPLEMENTATION RESPONSIBILITIES

PAYLOAD ORGANIZATION

- ASSURE SAFETY OF PAYLOAD
- IMPOSE & IMPLEMENT SAFETY REQUIREMENTS
- VERIFY COMPLIANCE WITH REQUIREMENTS
- PRESENT APPROVED FORMS AND SUPPORT DATA AT STS SAFETY REVIEW
- MAINTAIN SAFETY COMPLIANCE DATA PACKAGE FOR SHIPMENT WITH PAYLOAD

JOHNSON SPACE CENTER (JSC)

- RESPONSIBLE FOR FLIGHT SYSTEMS & FLIGHT OPERATIONS
- REVIEW PAYLOAD FOR COMPLIANCE WITH NHB 1700.7
- INTERPRETATION OF REQUIREMENTS
- REVIEW & DISPOSITION OF WAIVERS
- ASSURE INTERACTION AMONG MIXED PAYLOADS AND BETWEEN PAYLOADS & STS DOES NOT CREATE HAZARDS

KENNEDY SPACE CENTER (KSC)

- RESPONSIBLE FOR PAYLOAD GSE & GROUND OPERATIONS

STS PAYLOAD SAFETY DOCUMENTS

NASA HEADQUARTERS

- NHB 1700.7A, "SAFETY POLICY & REQUIREMENTS FOR PAYLOADS USING THE TRANSPORTATION SYSTEM"
- OVERALL POLICY & REQUIREMENTS APPLICABLE TO ALL STS PAYLOADS
- TECHNICAL & SYSTEM SAFETY REQUIREMENTS

JSC AND KSC

- JSC 13830, "IMPLEMENTATION PROCEDURE FOR STS PAYLOADS SYSTEM SAFETY REQUIREMENTS"
- SAFETY ANALYSES, DATA SUBMITTALS, ASSESSMENT REVIEW MEETINGS
- STANDARD FORMAT FOR REPORTING - HAZARD IDENTIFICATION, EVALUATION, RESOLUTION & TRACKING

FIG. 9

SUMMARY OF SAFETY REVIEW PROCESS

PHASE	TIMING	PAYLOAD ORGANIZATION'S SAFETY EFFORTS	PURPOSE OF REVIEW
0	Conceptual Design Established	1. Perform preliminary system level safety analysis.	1. Identify potential hazards and applicable safety requirements.
I	Preliminary Design Established	1. Refine and expand safety analysis. a. Define hazards. b. Define hazard causes. c. Evaluate actions for reducing or controlling hazards. d. Identify approach for safety verification. 2. Prepare a mission scenario. 3. Determine compliance with NHB 1700.7A.	1. Update safety analysis to reflect preliminary design. 2. Evaluate preliminary hazard controls and safety verification methods.
II	Final Design Established	1. Refine and expand safety analysis. a. Evaluate interfaces and mission procedures/timelines. b. Update hazard descriptions, causes, and controls. c. Finalize test plans, analysis procedures, or inspections for safety verification. 2. Determine compliance with NHB 1700.7A.	1. Update safety analysis to reflect final design. 2. Concur on specific hazard controls and safety verification methods.
III	Delivery to Customer	1. Complete safety analysis. 2. Prepare safety assessment report. 3. Complete all safety verification tests, analyses, and/or inspections. 4. Prepare safety compliance data package.	1. Approval of safety assessment report. 2. Review of safety compliance data package. 3. Identify open safety items.

FIG. 10

WAIVERS

- REQUIRED WHEN
  - PAYLOAD DESIGN/OPERATIONS DOES NOT MEET REQUIREMENTS OF NHB 1700.7A
- PAYLOAD ORGANIZATION SUBMITS WAIVER REQUEST TO MANAGER, PAYLOAD INTEGRATION OFFICE

WAIVER REQUEST FORMS

- PROVIDE RATIONALE SHOWING CLEARLY THAT THE PAYLOAD WILL BE JUST AS SAFE AS IF ALL NHB 1700.7A REQUIREMENTS HAD BEEN MET
  - TEST REPORTS
  - DETAILED DESIGN DRAWINGS
  - SCHEMATICS
  - QUALITY ASSURANCE METHODS
  - RELIABILITY DATA
- WAIVERS ARE SUBMITTED AND REVIEWED SEPARATELY FROM THE SAFETY REVIEW PACKAGE

FIG. 11

DESIGN REPORTS to NASA

Mechanical

- attachments, fasteners, stress corrosion
- shock and vibration loads
  (test verification + report)
- exp't layout and mounting structure drawings
- materials list (outgassing / offgassing), weights / volumes
- space qualified materials and components
- exp't weight and C. G.

Thermal

- max / min temperature limits
- emissivity / absorbtivity
- thermal control (ex : coatings) and isolation
- thermal model analysis
- space environmental degradation effects
  (ex : atomic oxygen in LEO)

Electrical

- power requirements and thermal control
- circuit diagrams (space qualified hardware)
- electromagnetic fields and interference effects
- rad hardened, MIL spec. components
- environmental control required
  (ex : mag. tape systems)
- vibration component protection

FIG. 12

REPORTS OF THE SYNDICATE WORKSHOPS

THE WORKSHOP ON EXTRACTIVE PROCESSES

REPORT OF THE SYNDICATE ON EXTRACTIVE PROCESSES

The group had a lively discussion of a wide range of topics to which all members of the group contributed. This report of the proceedings of that discussion will not be taken in precisely the same sequence, and this report reflects the syndicate leader's understanding of the main conclusions.

The group profited considerably from the presence of three representatives of potential Federal Government granting agencies who might be called upon for support of the fundamental components of space-oriented projects. After the large expense which appeared to have been incurred in the relatively simple experiments carried out by UTIAS during the pre-flight operations, there was some anxiety that the preparation for more sophisticated experiments might cost far more than normal University grants can support. A suggestion was made that funding for Cooperative Special Projects might be increased to cover the new and costly area of pre-flight space experimentation, or that the interpretation of the "socio-economic advantage" to be gained from Strategic Grants might be interpreted to include scientific involvement as a means of job creation and equipment production.

The topic of mineral processing brought out discussion of the potential of processing materials on the Moon. These are available in partially comminuted form, and will probably form the basis for metal production in the next century. The economic advantages of hauling construction material from the relatively low gravity Moon to a space station when compared with supply of these materials from the Earth appear attractive. For this reason processing experiments in the proposed space station might make use of a variable artificially-induced gravitational field as an approximation to conditions which might be found on the Moon. A number of physical properties of significant minerals could be investigated in such a study.

The field of ceramic studies appears interesting in the micro gravity environment. Comparison of slip-cast refractory objects made on Earth with those cast in the space station and subsequently fired on Earth would show the significance of particle sedimentation on the physical characteristics of the product. Such an experiment would involve relatively simple manipulations in space using virtually zero power.

Many interesting ceramic oxide systems can only be obtained as crystalline materials because of heterogeneous nucleation during cooling of the melts from which they are prepared. This could be eliminated under conditions of containerless fusion which could readily be achieved in microgravity. Due to the slow rate of homogeneous nucleation, it appears very probable that a number of new glasses of practical and scientific interest could be prepared in this way.

The development of the containerless fusion technique to include non-metallic phases holds out the possibility of multiphase studies, since containerless metallic systems have already been studied for many years. This extension would make it possible to obtain basic scientific information for e.g. metal-slag two phase systems, and slag-gas systems which would be of considerable interest to the metal-making industries of Canada, and which cannot at present be obtained on Earth.

The discussion of high temperature and vacuum systems made it amply clear that a fruitful discussion of proposals for future microgravity experimentation was hampered by a lack of understanding of the conditions aboard the Shuttle by scientists who must invent new experimental opportunities. It was therefore urged that the Canadian astronaut team be encouraged to hold in-depth discussions with interested research groups in an advisory capacity. It was also felt that the first exposure to some of the problems of microgravity research which most members of the syndicate experienced at this meeting was extremely helpful, and that the impetus which was gained as a result of this kind of workshop should be maintained by on-going study groups, such as the syndicate, which would devote their efforts to a few clearly defined experimental goals.

As an example, the state of motion of liquid samples, which could decide the possibility of significance of a number of experiments which may be proposed, could be well-defined at this juncture. A number of mass transfer experiments could then be considered in uniform and non-uniform temperature systems. One field where there seems to be a minimum of flow problems is in the proposed study of Ostwald ripening in a liquid matrix at uniform temperatures of solid or liquid disperse phases.

We would strongly support the suggestion made by Dr. R. Smith (Queen's) for a Gordon-type conference for Canadian researchers with a few invitations to foreign participants to be held in the summer of 1986 as a desirable follow-up of this most useful workshop.

Persons attending syndicate on Extractive Processes

Ben Alcock
Sankar Das Gupta
Jim Finch
Ralph Harris
Ian Inculet
Elaine Isabelle
Roy Littlewood
Alex McLean
Steve MacLean
Charles Masson
Don Milligan
Chris Pickles
Iain Sommercille
Dave Strangway
Jim Toguri
Roy VanKoughnett

THE WORKSHOP ON LIQUIDS & SOLIDIFICATION

Conference on Materials Processing in Space

Report of Syndicate on Liquids and Solidification

This session began with a brief report by Dr. Fred Lipsett concerning a Gordon Conference on Materials Processing in Space that he attended in August. He reported that the U.S. space program has funding of about $\$35.\times 10^6$ per year for work related to materials processing in space. Studies range from drop tower experiments to full space flight experiments. Dr. Robert Naumann heads a group of about 50 Ph.D.'s working in this area at Marshall Space Flight Center, Huntsville, Alabama. Two significant results achieved in the program to date are the growth of single crystals of mercury iodide and single protein crystals.

Dr. Kenney-Wallace pointed out the great need for new materials, especially single crystals, in the field of opto-electronics in which she works. She expressed the hope that materials processing in space will lead to the production of better materials than those currently available.

Discussion quickly turned to the question of funding. Dr. Fred Weinberg pointed out that a meeting sponsored by NRCC was held in June of 1982 at the University of Toronto to discuss possible work on materials processing in space. Several of the persons who attended the 1982 meeting were present at the current syndicate. The 1982 meeting showed that there is a substantial number of persons in Canada interested in carrying out research related to materials processing in space, and a list of topics of interest was drawn up. However, no sources of funding specifically for the proposed studies have become available. It was pointed out that NRCC does not have a mandate to fund fundamental research and that NSERC is the only source at present for funds to support the extensive ground-based research necessary to support experiments on materials processing in spaces. The areas of interest remain as in 1982, as follows:

1. Growth of single crystals, especially of semiconductors, by all applicable methods.
2. Experiments in fluid flow.
3. Floating zone melting.
4. Containerless solidification experiments.
5. Bubble nucleation and growth in liquids, including production of metal foams.
6. Suspensions of particles in liquids.
7. Vapour transport for crystal growth.
8. Eutectic freezing.
9. Marangoni convection.
10. Surface tension forces.

The syndicate established a committee to discuss priorities and cooperation in order to promote work in the areas of interest outlined previously. University-Industry cooperation is planned. Dr. Fred Lipsett of NRCC was appointed chairman pro tem of this committee.

It was proposed that a conference be held in mid-1986 at Queen's University on the topic "Advanced Materials Processing: the Effect of Gravity."

J.W. Rutter

THE WORKSHOP ON MATERIALS FABRICATION

REPORT OF THE WORKSHOP ON 'MATERIALS FABRICATION'

by

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**Department of Metallurgy and Materials Science
University of Toronto

The group dealing with materials fabrication met on Wednesday, 23 October 1985, from 1400 hours to 1615 hours. Fifteen (15) people were in attendance, representing industry (7), universities (4) and federal government (3). The group first reviewed the tasks that had been presented to all syndicate groups by the organizers, and then went on to consider the technical issues that might be dealt with under the title of 'Materials Fabrication'.

The group agreed on two classes of topic for discussion. The first concerned opportunities to fabricate materials or structural assemblies in space for later return to earth. The group opted to include not only opportunities that were driven by long term commercial considerations but also opportunities to use the unique features of the space environment to perform basic science experiments in space that could not be performed on earth. In addition to these discussions, the group expressed a need to consider materials problems arising from Canada's more general involvement in space technology, and particularly problems associated with the design, fabrication assembly and use of large space structures. The syndicate leader reminded the group that proposals were now before government for Canadian participation in NASA's permanently manned space station project, as well as other major projects involving remote sensing and solar arrays. Irrespective of which of these options are selected, the government obviously needs to be confident that (a) as a nation we have the technology to design the appropriate structures, (b) we can build them, (c) they will meet the basic design requirements, and (d) they will meet the performance requirements and function reliably in the harsh space environment for their intended design lives. Consequently many problems may be anticipated, and these should be addressed at an early stage through appropriate materials evaluations, component or structural design, development, and performance evaluation studies. Logically these studies should be planned and executed before detailed design and fabrication of actual flight hardware.

The two areas of activity discussed by this group can therefore be described as materials fabrication in space, and materials fabrication for space. These discussions are described in the following two sections.

A. Materials fabrication in space

In order to avoid duplication with the other three syndicate groups, it was agreed that this group would attempt to exclude from discussion processes involving extraction, liquids and solidification, and semiconductors. Accordingly the group concentrated on vapour phase processing of materials or processing of materials in the solid state. However, in practice this was not achieved and some overlap with the other groups occurred, as will be seen later. In setting the scene for these discussions Prof. H. King

(Technical University of Nova Scotia) pointed out the cost constraints associated with transportation of bulk quantities of material to and from the space environment, and suggested that the group should perhaps concentrate on materials with high specific value (value per gram). Dr. Prasad (B.M. Hitech) suggested that space offered fewer opportunities for solid state processing of materials than liquid or vapour phase processing. However, the fact that containerless processing was possible would allow direct observation of solid state processes such as sintering.

Following fairly extensive discussion six specific interests were identified, as follows.

1. Prof. H. King (TUNS) explained his interest in the processing of ultra-fine metal and ceramic powders. When powders of widely differing densities are mixed on earth, the mixture acts as a fluid with the denser particles separating out under gravity forces. Space processing should allow more homogenous mixtures to be obtained, and as a result of shorter diffusion paths less time would be required during sintering to achieve complete homogenization.

2. The above discussion led eventually to discussion of the preparation of solid solution ceramics. Prof. King explained the problems associated with the preparation of semiconductor ceramics consisting, for example, of lanthanum oxide containing 20% strontium. Nitrate solutions can be prepared by dissolving lanthanum and strontium in nitric acid. These solutions are then freeze dried or spray dried to produce finely dispersed two phase mixtures of nitrates which can be calcined to produce mixed oxides, compacted and finally sintered to produce solid solution oxides. However 1-g processing produces relatively coarse oxide particles of about 15 μm, and the times required to achieve full homogenisation are correspondingly long. If the spray drying could be performed in space, the high vacuum and infinite pumping capacity might lead to ultra-fine particles of high purity. If the particle size could be reduced to say less than 3 μm, the sintering times required for densification and homogenisation would be substantially reduced. These conducting or semiconducting ceramics could be used for making heating elements capable of operation in highly oxidizing environments, or to manufacture heat resistant cables, wiring, integrated circuits and memory devices. Prof. King indicated possible industrial interest in this technology, although the ideas were clearly at an early stage of development and needed further work.

3. Mr. M. Mountford (Univ. Toronto) explained his interest in the processing and properties of composite platings. These were electro-platings containing a dispersoid of hard particles for wear and fretting resistance. The particles are thought to form complex oxides under frictional wear conditions, and if the oxides exhibit lubricating properties friction and wear are reduced. Typically, these coatings contain up to about 20% of such hard particles depending on particle density. Larger amounts are difficult to achieve because of sedimentation which occurs in the plating bath. Other forms of processing such as plasma spraying are able to provide greater particle contents but they were thought to be more difficult to control than plating and were essentially line-of-sight processes. Thus the deposition of wear resistant coatings on the inside surfaces of long narrow tubes or hollow shafts was difficult. Space processing might allow new plated coatings to be obtained containing dispersed particles having a wide range of densities and oxide forming characteristics (e.g. W, Ti, Cr). While space processing might not be viable

on a commercial basis, it would allow new materials to be obtained for performance studies, and hence provide a stimulus for the development of similar processes that could be applied on earth.

4. Dr. Prasad (B.M. Hitech) described several classes of material that he thought might benefit from containerless processing in the high purity environment of space. In particular he thought the space environment might allow sol-gel technology to be used to produce high purity glasses and composite ceramics. These materials, he suggested, might find applications in optical fibres, laser devices and other articles used in microelectronics and communications. As explained earlier, the range of composite ceramics available through terrestrial processing is limited by sedimentation effects, and particularly where liquid phase processing is involved.

   Highly polarizing materials based on neodymium doped glasses are needed for laser applications, but doping is limited by gravitational effects on earth. Processing of such materials in space, along the lines described earlier by Dr. King, might allow higher degrees of doping to be achieved.

5. Dr. Prasad continued his discussion by indicating the wide range of fibre or whisker (e.g. SiC, Si_3N_4) reinforced materials that might be processed in space. The main benefits of space processing were the high purity environment and absence of gravity induced separation of particulate solids. A much more thorough investigation of candidate systems would be required before specific systems and experiments could be proposed.

6. In closing this discussion Dr. Weatherly (Univ. Toronto) suggested that if fine particle production and sintering is an area to be recommended then we should also consider opportunities to produce porous materials in space. Sintering is traditionally a process used to produce dense materials, but the space environment might also allow high purity porous materials to be produced for applications such as filters or catalysts.

The group concluded that powder processing in space merited further consideration and that more detailed studies were required to allow these preliminary thoughts to solidify as firm research proposals.

B. Materials fabrication for space

To stimulate this discussion the syndicate leader showed a number of viewgraphs listing some of the obvious questions related to the design, fabrication, assembly and use of large space structures. Included were questions on the size and mass of the proposed large space structures, whether it would be feasible to fabricate on earth and transport the finished structure into space as a pre-assembled unit, or whether it would be necessary to assemble in space using sub-units manufactured on earth. The leader pointed out that for design purposes a great deal of material property data would be required on the light-weight, high stiffness materials required to build such structures. He suggested that the candidate materials would include a wide range of glass, Kevlar and graphite reinforced composite materials, as well as metal matrix composites, hybrid metal/non-metal laminates such as ARALL, and the new high stiffness aluminum alloys from the Al-Li system. He noted that, Canada has little experience both in the fabrication and use of these materials, and that extensive data bases do not exist in this country. If joining is required, then a great deal of information will be needed on candidate joining techniques, how they are influenced by the space environment, and the properties of the joints produced.

In order to provide confidence that large space structures will perform satisfactorily over the full design lifetime, a great deal of additional data will be required on the stability of such materials in the harsh environment of space. The paper by Prof. Tennyson (U.T.I.A.S.) presented during the morning session had given a brief indication of the serious forms of degradation that could effect resin matrix composites, and provided an initial indication that more stable structural materials or protective coatings might be needed for structures required to survive 20 - 30 years in space.

Finally, the leader explained that major problems could be expected in the mechanical qualification of these large space structures. Because of constraints on mass, these structures would probably not be dimensionally stable on earth, and therefore the mechanical qualification on earth prior to launch would stretch our ingenuity. These problems would be even more complicated if the full structure could only be assembled in space from its constituent elements.

Dr. Doetsch replied by saying that in the case of the space platform, the component structures would be both large and heavy, and that each would probably be comprised of several modules designed to lock together in space. On orbit assembly of pre-fabricated units would certainly be required. Estimates varied on the number of shuttle launches required, but he indicated that 8 - 9 would be a reasonable estimate. He thought that the structure would likely involve truss type sub-units fabricated from either organic matrix composites or metals. He indicated that the space platform would be designed to a 20-year life requirement, and therefore light alloy structure would be a strong possibility because of its greater environmental stability. Joining requirements would be influenced to a great extent on the size of the truss units used. Two sizes are under consideration at the present time, a five foot cube truss that would fit into the orbiter, and a fifteen foot truss that would not. Clearly, quite different joining problems will follow from this decision.

Prof. Hansen (UTIAS) explained that environmental degradation depended on altitude. For low earth orbit degradation was due primarily to bombardment by atomic oxygen and involved either erosion, oxidation or a combination of the two. Higher altitude degradation was due primarily to radiation damage from ultra violet rays and high energy electrons. Earlier, Prof. Tennyson had included impact damage from micrometeorites among the forms of damage of concern. Oxygen induced degradation in low earth orbit is also likely to affect metals if the naturally occurring oxide films are not adherent and therefore not protective. Prof. Hansen pointed out that even solar cells suffer forms of space degradation, and he reported a comment (now 5 years old) from a NASA scientist that no structural materials or coatings would survive the space environment for more than five years. However, Prof. Hansen was not sure whether this was reliable information or whether the problem, if real, still existed.

Dr. Doetsch reviewed some of the results from the NRC/DOC materials degradation studies performed on shuttle flight 41-G in October 1984, and explained that certain metallic coatings had provided a degree of protection to graphite-epoxy composites. However, he noted that where flaws existed in the coatings the degradation of the exposed composite was particularly severe. This phenomenon appears at first hand to be analogous to crevice corrosion which occurs at flaws in protective coatings on terrestrial metallic structures, and might indicate some form of electrochemical phenomenon.

There was extensive discussion on these problems, and the conclusion reached was that there was an urgent need for a great deal more information on these matters. Activities are needed in the following areas:

1. A clearer understanding is required of the modes and rates of degradation of structural materials in space.
2. An extensive data base is required on the mechanical properties of environmentally degraded materials.
3. Comparative studies are required on candidate structural materials to identify those which are less seriously affected by space.
4. A better understanding is required of the physical requirements for protective coatings. Methods need to be developed for applying protective coatings both on earth and in the space environment.
5. In developing and evaluating protective coatings, attention needs to be focussed on the problem of repair of coatings. It must be possible to repair coatings on orbit, and in such a way that the quality of the space environment is not compromised.
6. Because of the present limited access to space for long duration experiments an urgent need exists to develop new and improved facilities on earth to perform simulated space exposure tests. A particular need exists to develop facilities capable of simulating high energy particle (electron and ion) bombardment.

The remaining time was devoted to joining in space. Based on the comments made earlier by Dr. Doetsch, the group concluded that joining during the initial assembly of large structures would likely involve mechanical methods. However, joining techniques were considered important for the repair of space structures and systems. In this respect a wide range of processes was thought to be possible, and these included brazing, adhesive bonding, diffusion bonding and perhaps fusion welding in its various forms. Again, more detailed studies are required to be able to predict the most likely repair scenarios and to investigate the wide range of materials, structural configurations, and processing that might be applicable in a space environment. The leader pointed out that the full range of inspection devices would probably not be available in space and therefore quality control and qualification of repairs would pose interesting problems.

Concluding remarks and recommendations

Future involvement in international space programs will likely be fraught with delays, set-backs, frustrations and perhaps major catastrophes unless the work proceeds in a careful and controlled manner. Perhaps the most urgent need at the present time is the nurturing of a space research and technology community in Canada working towards well defined goals. The development of the major items of space hardware mentioned earlier would provide the goals. If the space platform concept becomes a reality, materials fabrication for space rather than in space would seem to be the more pressing problem. The space community is seen to consist of a substantial group, or infrastructure, of scientists and engineers from universities, industry and government, performing in the first instance exploratory research aimed at the better definition of problems and the development of a basic science and technology program addressing these problems. Much of this basic work needs to be done in ground-based laboratories before studies or applications proceed in space.

The research scientists and engineers who have participated in this workshop represent the materials science and engineering community. They have indicated in very real terms their interest in participating in a Canadian space program, and the type of work they are able to perform. The group indicated that it had found this workshop to be extremely useful, and asked if similar meetings could be arranged on a regular basis. It was suggested that regular meetings held once each year would be adequate.

In conclusion the authors of this report would like to add that many of the opportunities and problems identified here need further development and definition. However, progress can only be made if the interested community is kept fully informed on developments in Canadian government space policy and on the wide range of projects and related experiments already in progress. This type of liaison, coordination and planning activity is manpower intensive, and requires a properly manner programme office or central agency. Based on the discussions heard during this workshop, we conclude that the university community is particularly keen to participate in space technology. Industry appears to have adopted a reactive mode, while government has contributed primarily in a catalytic mode. We are led to the opinion that the leadership role will fall to higher authorities in government if Canadian participation in space is to continue.

W. Wallace

G. Weatherly

29 October 1985

Persons attending syndicate on

Materials Fabrication

Peter Bolden
Jack Cameron
Karl Doetsch
Tony England
Brain Hill
Dave Kendall
Hugh King
Ian McDiarmid
Monty Mountford
Ralph Nicholls
Barry Payne
Bill Wallace
Mike Watson
George Weatherly
Paul Wycliffe

THE WORKSHOP ON SEMICONDUCTORS

Symposium on Material Processing in Space
(Toronto, October 21-22, 1985)

Semiconductor Syndicate Leader Report

Richard Boudreault
Manager, MPS Technology Development
Canadian Astronautics Limited

Attendees at the meeting:

Name	Institution	
R. Boudreault	CAL	Syndicate Leader
R. Tennyson	UTIAS	Rapporteur
J. Davis	Noranda Research	
D. Johnston	Alcan Research	
P. Kumar	NRCC-NAE	
L. Secord	DSMA/ATCON	
G. Saintonge	MPB	
B. Bollong	Cominco	
W. Zingg	U. of Toronto	
T. Croil	Consultant	
M. Sullivan	ORF	
D. Zincik	CRC/DOC	
N. Yemendijian	TUNS	
R. Crouch	NASA/MPS Office	
H. Law	Honeywell	
N. Salanski	UTIAS	

Table 1 who's who

Abstract

Seventy five percent of the syndicate members were industrial/governmental representatives. With this in mind, it is understandable that most of the discussion dealt with policy and organization. The goal of most members was to get MPS semiconductor activities underway while respecting the commercial and economic concerns of their "raison d'etre".

Concerns were raised about the time period required between development and the introduction of space produced semiconductors to the market. It was generally felt that such a long period was often a disincentive to experimenters. This also implies the economic present value of space produced materials becomes negligibly small. This is the main reason why industry does not provide more of the funding for MPS. It is also recognized that a thorough scientific data base is required to enable industry to create commercial semiconductor MPS endeavours. The non-recursive cost of the MPS semiconductor research, necessary to establish the scientific data base, should not be considered applied R & D since this would significantly decrease the present value of any resulting commercial semiconductor activity in space.

It is recognized that scientific data base development, as opposed to technological data base, is not the duty of industry. It falls upon the government to finance such work and to the universities to execute it. It is not certain that a scientific data base has to be independently developed in Canada, industry may well be able to use existing NASA or ESA data bases. Since limited communication between industry and universities exists in Canada, Canadian scientific work may not find its way into the Canadian MPS economy. These situations can be corrected in two ways, the first consists of creating a forum where industry, government and university could meet and discuss; the second consists of participating with other countries in the development of a widely published scientific MPS data base.

Microgravity Environment for Semiconductor MPS Works

The many advantages presented by microgravity were discussed, the reduction of convection, improvements in transport phenomena, etc. were found to be attractive characteristics. "New" phenomena, such as surface driven thermocapilarity, unconventional crystal growth, accelerated crystal growth are considered important research directions.

A strong opinion of the syndicate was that microgravity should not be considered as the sole usable characteristics of the space environment. Vacuum was deemed an important characteristic of the new environment. New organic semiconductors would benefit greatly from the 10^{-12} torr vacuum available behind a molecular shield on the shuttle. Semiconductor research should consider the whole spectrum of characteristics available through space processing. Other commercial advantages of space should be studied (ie. fabrication of larger monocrystaline detector grade semiconductor wafers).

Only a few electronic crystal experiments in space have been carried out. These demonstrated the advantages of space processing, but also identified some of the problem areas. Commercial opportunities lie in the exploration of these questions and for this reason Canada should cooperate with other countries in researching new phenomena instead of entering in the race towards an independent scientific data base. On the other hand, the technical data base of other countries such as the U.S. are not accessible and may force Canada to support an independent effort in commercial MPS.

Cooperation with other countries must encompass scientific and engineering aspects in order to ensure Canadian capability in these areas.

It was regarded important by the syndicate that researchers have freedom selecting the materials they wish to study. They should however, keep in mind that the materials should yield a high added value for commercial space processing.

Canadian MPS Resources

It is understood that Canada has limited resources in MPS. Not having launch capabilities implies limited access to space. This access to space was deemed a significant problem by the members of the syndicate. It was also mentioned that duplication, in the form of similar experiments flying different hardware may arise. The small size of the Canadian MPS community and its diversity was also recognized. The significant difference between the industrial goals and the research community goal's were reviewed: it was understood that the private enterprise cannot financially support non-commercial activities.

To alleviate these problems it is suggested that a forum be created from the actual NRC-NAE μ-g committee (Space Station). It should receive an extended mandate; Correlating the needs and requirements for scientific and technical MPS data bases, matching people and organizations with MPS similar interests, disseminating information about international activities specifically in semiconductor work, arranging, whenever possible, contact between university and industry researchers, trying to organize research groups with similar interests into cooperating on multi-user facilities when possible without neglecting the important role of the single user facility (due to its low cost and simplicity). To summarize, the role of the forum would be to recommend actions to the governmental agencies and pool resources from the Canadian MPS activists.

To facilitate access to space it is recommended that governmental agencies purchase a large batch of GAS Cans or Hitchhiker Canisters and distribute these flight opportunities at regular intervals (eg. 6 months). The opportunity to fly an experiment on such a flight would be presented to the Canadian MPS community (Gov.'t, industrial and university) via RFP's at periods ranging from 1.5 to 2 years previous to flight.

It was also felt that it is too early to decide on which aspect of semiconductor research Canada should develop and that a future conference should be organized to discuss this subject.

Conclusion

The conclusion are summarized in Table 2.

Semiconductor MPS

Situation

- Requirement exists for a scientific data base and a technical data base in semiconductor MPS.
- International competition in MPS research is futile.
- Access to space is difficult and will present problems.
- There is no voice for the MPS community in Government R & D decisions. "A void exists."
- Canadian MPS resources are limited.
- Too early to decide on orientation for semiconductor MPS research for Canada.

Suggestions

- Create a scientific data base by doing ground and space basic research in cooperation with other nations. A parallel technical data base in commercial space MPS should be developed independently. Canada's contribution to international microgravity programs should be scientific and technological in nature.

- A forum should be created to increase communication and interaction between MPS community members, to pool resources and ease access to the microgravity/space environment. This forum would advise the gov't agencies on the needs and requirements of the MPS community and should be composed of representatives from the academic, private and public sectors.

- Access to space be eased by having frequent low-cost and low red-tape flights aboard a "Hitchhiker" type facilities. These flight opportunities should be offered to the MPS community via RFP's about 1.5 year before the flight.

Table 2 Summary of the Situation and suggestions from the Semiconductor Syndicate

APPENDIX 1

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