EVALUATION OF THE SPACE STATION USER DEVELOPMENT PROGRAM BY MEANS OF CASE HISTORIES

Final Report

SSC Contract No. 31016-0-6019/01-SW

December 15, 1990

Submitted to:

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Executive Summary

This report describes the findings resulting from case studies of seven projects supported by the User Development Program of the Canadian Space Agency. The key success factors have been identified with respect to each of the program objectives. Strengths and weaknesses have also been noted.

The following cases were studied.

	Project	Contractor
1.	Performance of Exploratory Experiments for Ceramics Processing in Space	AASTRA Aerospace Inc.
2.	Microgravity Processing of Materials for Infrared Optics and Sensors: Development of a Research Program.	B.M. Hi-Tech Inc.
3.	To Study the Feasibility of Using Bubble Detectors for Dosimetry Applications in Space.	Bubble Technology Industries
4.	Development of a Floating Zone Semi-Conductor Manufacturing Facility in Microgravity.	Canadian Astronautics Limited
5.	Development of Experiments on Crystal Growth of GaAs(In) by Liquid Phase Electro-Epitaxy (LPEE) in Microgravity.	MPB Technologies Inc.
6.	Structure of Flocculated Polystyrene Latex Under Constant Shear.	Prof. D.E. Brooks
7.	A Study for the Development of a Compact Gradient Freeze Furnace for Controlled Growth of High Quality Crystals.	ThermaZone Engineering Inc.

Our review concludes that the program is well received, is well managed and is achieving its objectives. A cadre of experienced investigators is being developed, many of whom have flown with their experiments in microgravity conditions. It is important to maintain such a group in order to ensure that Canada has the capability to use Space Station when it becomes available.

The lack of accommodation on the Shuttle has resulted in a need to provide alternate vehicles for providing microgravity conditions. Program management has successfully addressed this problem. Suggested changes for the future relate to changing circumstances rather than any inherent problems in the program.

Based on our findings we offer the following recommendations.

Recommendation 1.	**When commercialization is the main objective, the UDP should concentrate its resources on small companies that can demonstrate their investigations in microgravity will lead to improved terrestrial processes or products, for example, companies with a manufacturing capability who can leverage the know-how acquired through the UDP involvement to improve terrestrial products or services.**
Recommendation 2.	**The UDP should proceed with caution in the support of infrastructure hardware in cases where a need is not clearly identified by a user.**
Recommendation 3.	**In the light of experience to date, the UDP should focus its main effort in regard to expending knowledge on university-based projects that lead to the award of an M.Sc. or Ph.D.**
Recommendation 4.	**The UDP should consider holding a workshop to bring together the PI's who are working in microgravity with the leading PI's in the same field. This could be run as an independent workshop, or arrangements could be made with a national scientific society to devote one session at its annual conference to reports on microgravity investigations.**

Recommendation 5. In the near term, the UDP should be wary of supporting the development of hardware which can only be used in the Shuttle or on Space Station.

Recommendation 6. The UDP should develop a strategy for encouraging the use of hardware developed by the program.

Recommendation 7. Program management should continue to explore and pursue all available opportunities for access to microgravity.

Recommendation 8. Every effort should be made to reduce the "dead time" between successive phases of a project.

Recommendation 9. The UDP should apply its best effort to obtaining a lead time of one and one half years for each Announcement of Opportunity.

Recommendation 10. The UDP, in conjunction with CAPO, should examine the reporting requirements for space experiments with the aim of reducing the paper work-load on PI's.

Recommendation 11. Program management should determine the most appropriate course of action that will permit the advisory committees to be involved in the evaluation of all proposals for the UDP. When a suitable process has been identified, it should be implemented.

Recommendation 12. An astronaut should be included in the membership of the Space Sciences Advisory Committees that are involved in evaluating proposals to the UDP.

Recommendation 13. The UDP should develop a strategic plan that takes account of the prospects for access to microgravity, the best use that can be made of the microgravity platforms, and the most effective process for ensuring that the best investigators have an opportunity to participate in the program.

1. INTRODUCTION

This report is submitted in fulfilment of the requirements of Supply and Services Contract No. 31016-0-6019/01-SW entitled "The Evaluation of the Space Station User Development Program by Means of Case Histories".

2. OBJECTIVES OF THE ASSIGNMENT

The study objectives are to:

- identify key success factors for contracts issued to April 1990; and,
- assess the impacts resulting from specific contracts.

3. BACKGROUND

Early in the planning for Canadian participation in the international Space Station Program it was recognized that significant opportunities exist for investigators to make use of the reduced gravity encountered on Shuttle flights and ultimately on the Station itself.

This recognition led to a number of studies, first to identify possible investigations and later to focus on those which showed the most promise for success in both technical and commercial terms.

These studies resulted in the establishment of the Space Station User Development Program (UDP) in March 1986. The goal of the UDP is to lay the scientific and technical groundwork for the use of Space Station Freedom by Canadian investigators. Funding was set at $75M to the year 2000.

The objectives of the UDP are:

- to identify promising areas of utilization of the space station environment with potential for eventual commercial and economic opportunities;
- to support studies and experiments to expand knowledge of relevant phenomena in the space environment and to demonstrate the possibilities of the proposed applications;
- to assist in the definition and development of hardware for eventual use on the space station; and,
- to provide opportunities to access the microgravity environment on a regular basis, including the use of microgravity aircraft, rockets and other spacecraft.

Financial support for the UDP is included in the budget for the Space Station Major Crown Project (MCP). Program management lies within the Space Science Program, which is outside the MCP.

Since accommodation for experiments involving hardware is severely restricted in the Shuttle, and Space Station is not expected to be available before the turn of the century, the User Development Program began by purchasing flights on the US KC-135 aircraft. This provides about 20 seconds of about 0.01g. In addition, a Canadian T-33 has been modified to accommodate experiments involving short duration in low gravity. Space is limited in this latter aircraft.

The UDP is joining with Transport Canada in the operation of a Falcon-20 provided by the

Department of National Defence. The departments will share the use of the aircraft, each for its own separate program. For the UDP, the aircraft will be modified to accommodate microgravity experiments which will have about the same level and duration as the KC-135. This will provide greatly improved access to microgravity, and should increase the level of participation in the program. The Falcon-20 will be able to accommodate 4 experiments; an expected lead-time of 1-2 weeks should prove a major attraction to users. Arrangements for the use of drop tubes are also in train.

The UDP solicits participation from both industry and the academic community. The policy is to issue contracts in phases, with Phase I a study phase. The phased approach is used to control the project and make sure that any deviations from expectations are identified as they occur. Industry contracts focus on economic payoffs, while those awarded to university Principal Investigators (PI's) are in support of the acquisition of new knowledge. Phase I contracts to industry cost about $80,000 and those to universities about $50,000. Proposals from industry are reviewed by government specialists; those from university often involve advice from peers beyond the government sector. The UDP follows the same philosophy in conducting progress reviews. In situations where there is some doubt about the ability of the contractor to meet performance standards, go/no-go decision points are included in the contracts.

The UDP also issues Announcements of Opportunity (AO) for access to microgravity in a number of vehicles. These call for proposals to make use of

- Russian MIR Space Station:
- Space Shuttle;
- Space Hab;
- KC-135;
- T-33;
- rockets; and,
- satellites.

Proposals are accepted from investigators already in the program or from new users.

In the case of the KC-135 an astronaut or a UDP staff member is assigned to each successful proposal in order to ensure that the experiment is suitably designed. To ensure a successful experiment a "seasoned flyer" is assigned as a back-up to the PI in case the latter succumbs to air sickness.

A number of contracts have been issued during the last few years in pursuit of the program objectives.

A list of current contracts is given below.

UDP User Contracts for FY 1990/91 as of March 1990

	Company	Subject
1.	AASTRA Aerospace Inc.	Ceramics
2.	"	Proteins
3.	McGill University	Modelling
4.	Advanced Materials Eng. Centre	Ceramic Slip Molding
5.	Concordia University	Flames
6.	Laval University	Fractals
7.	"	Proteins
8.	University of Saskatchewan	2-phase flow
9.	ThermaZone Engineering Inc.	Furnace
10.	ORTECH International	Sol-gel
11.	"	Magnetic Ceramics
12.	"	Liquid Crystals
13.	SED Systems	CMT
14.	Bristol Aerospace Ltd.	QUESTS
15.	McMaster University	Crystallization
16.	University of Manitoba	Solidification
17.	University of British Columbia	Flocculants
18.	"	Modelling
19.	B.M. Hi-Tech Inc.	Glasses
20.	Bubble Technologies Industries	Detectors
21.	Thompson & Neilson	Dosimeters
22.	"	Ariene Tech Satellite
23.	Ceramics Kingston	SiC Fibres
24.	MPB Technologies Inc.	LAMPS
25.	"	CHAMPS
26.	Electrofuel Manufacturing	Ostwald Ripening
27.	Fiberglas Canada	Foams
28.	Queen's University	Eutectics
29.	Alberta Laser	Welds
30.	Crystar	Beta Barium Borate
31.	University of Western Ontario	Droplet Breakup

Source: UDP office.

This report describes the histories of seven projects supported in the recent past. The information obtained from these case histories is the basis for our conclusions and recommendations in meeting the study objectives.

4. METHODOLOGY

In consultation with the Scientific Authority (SA) for this contract, seven projects were selected for study. These were considered to represent the spectrum of activities supported by the program. As noted above, many are phased projects, so that a cut-off time had to be identified to place a cap on the collection of historical information.

The person responsible for the contract in each organization was visited to obtain information on the contractor's perspective in relation to the value of the work to the contractor. Information was also sought on the administration of the contract - from proposal to submission of the final report.

Subcontractors and the scientific authorities assigned to the individual contracts within the UDP were also contacted. The list of persons contacted is given in Appendix VIII.

Case histories for each of the seven projects listed below have been compiled and are to be found in Appendix I to VII.

	Project	Contractor
1.	Performance of Exploratory Experiments for Ceramics Processing in Space.	AASTRA Aerospace Inc. 1685 Flint Road Downsview, Ontario M3J 2W8
2.	Microgravity Processing of Materials for Infrared Optics and Sensors: Development of a Research Program.	B.M. Hi-Tech Inc. P.O. Box 97 20 Stewart Road Collingwood, Ontario L9Y 3Z4
3.	To Study the Feasibility of Using Bubble Detectors for Dosimetry Applications in Space.	Bubble Technology Industries Highway 17 Chalk River, Ontario K0J 1J0
4.	Development of a Floating Zone Semi-Conductor Manufacturing Facility in Microgravity.	Canadian Astronautics Limited 1050 Morrison Drive Ottawa, Ontario K2H 8K7
5.	Development of Experiments on Crystal Growth of GaAs(In) by Liquid Phase Electro-Epitaxy (LPEE) in Microgravity.	MPB Technologies Inc. 151 Hymus Blvd. Pointe Claire, Quebec H9R 1E9
6.	Structure of Flocculated Polystyrene Latex Under Constant Shear.	Prof. D.E. Brooks Department of Pathology University of British Columbia Acute Care Hospital Westbrook Mall Vancouver, B.C. V6T 1W5
7.	A Study for the Development of a Compact Gradient Freeze Furnace for Controlled Growth of High Quality Crystals.	ThermaZone Engineering Inc. 2285 St. Laurent Blvd., Unit D8 Ottawa, Ontario K1G 4Z7

5. SUMMARY OF FINDINGS - STRENGTHS AND WEAKNESSES

Our interviews have identified strengths and weaknesses as perceived by program participants. We provide these in the expectation that the UDP can build on the strengths and take steps to overcome weaknesses.

5.1 Strengths

- The UDP has nurtured rather than directed industry proposals, and is therefore more likely to use Canadian industrial strengths and more likely to result in spin-off.
- The UDP supports companies with manufacturing capabilities and puts them in a position to leverage advanced technologies developed under the UDP.
- Willingness to support small companies if ideas and people are good.
- Continued funding based on performance.
- Phased approach.
- Flexible management.
- Good administration.
- A lot of activity for funds expended.
- Enhancing international stature.

5.2 Weaknesses

- Too much time taken in the Supply and Services Canada process.
- Too much time between phases.
- Logistics costs for KC-135 difficult for a small company to bear.

- Limited users for equipment designed for Shuttle/Space Station.
- Inadequate mechanism to link hardware developers with users.
- Some feel UDP is overly focused on hardware development which is likely to become obsolete as flight opportunities change.
- No funding to carry projects to commercialization.
- There is a perceived ambivalence with respect to the balance between science and development of products and services with commercial potential.
- There should be a strategic plan equivalent to that produced by NASA.

6. BENEFITS AND SPIN-OFFS

6.1 Benefits

6.1.1 AASTRA Aerospace Inc.

Phase I and its economic analysis convinced AASTRA that it was worthwhile to get into the manufacture of advanced ceramics and led directly to its acquisition and turn-around of financially-troubled ALMAX in 1988.

The UDP has helped to position the company with respect to what it feels are significant potential commercial opportunities in the field of advanced ceramics, particularly in the bio-materials market for products such as bone implants.

The company's involvement in UDP advanced ceramics work put AASTRA in a position to successfully pursue UDP protein crystallization work. This work in turn exposed the company to dynamic light scattering technology, which is applicable to the analysis of ceramic powders and may improve quality and processing control by enhancing the ability to identify particle size distribution.

The company feels that its UDP involvement has allowed it to employ materials researchers to study advanced processing concepts and to develop a strong engineering team capable of providing engineering services in hardware development for space applications.

6.1.2 B.M. Hi-Tech Inc.

The UDP has been instrumental in supporting and nurturing B.M. Hi-Tech, a small, entrepreneurial Canadian company. B.M. Hi-Tech has evolved from a fledgling company with little microgravity know-how into an organization with capability and expertise in advanced glasses, one of a small number of world manufacturers of fluoride glasses. The company's capability has evolved to include:

- integrated facilities and expertise at one location for the production of glasses, ceramics and transducers;
- competence to develop new materials, incorporate them into components and devices and identify practical production techniques;
- expertise in the design and support of complex process hardware and related automation;
- the ability to market its products and services domestically and abroad; and,
- a strong world-wide network of contacts in advanced ceramics and glasses and related disciplines.

6.1.3 ThermaZone Engineering Inc.

In the case of ThermaZone, the UDP contract was responsible for the successful formation of what is now a viable company. The sub-contract with Queen's University has brought a faculty member and graduate students into the project, and therefore increased industry-university cooperation within the microgravity user community. The knowledge and capability in software development and control systems that led to the award of the contract are the same skills that are the basis of its main product. Thirteen of the fifteen employees are working on developing products. Two are working with the furnace developed by the UDP.

6.1.4 Others

Companies who have developed hardware infrastructure are optimistic they can market either a product or specialized components. The hardware developed by UDP has involved some technological advances that can be marketed outside the program to specialized users. One benefit is the enhancement of Canada's image as a producer of high technology items, and the resulting international cooperation in space programs.

6.2 Spin-offs

B.M. Hi-Tech Inc. has developed three pieces of hardware under this program. The first is a manual glass processing furnace for the KC-135 aircraft which heats small samples to temperatures up to 1000 degrees C, and allows quenching of samples in a short period of time. This furnace is operational and is available for use by others. B.M. Hi-Tech Inc. also developed a second, automated furnace for glass processing for T-33 aircraft use. This unit features a triple containment system to heat small samples to temperatures up to 1000 degrees C, and also allows quenching in a short period of time. This hardware flew on the T-33 in March 1990 and is operational. Third, B.M. Hi-Tech Inc. developed an aerodynamic levitator and heating facility. This unit is a ground-based levitator with infra-red heaters designed for containerless processing to temperatures up to 1200 to 1500

degrees C. A prototype is complete and the company has a request for licence in process with NRC. UDP funding for the aerodynamic levitator has been terminated.
The company has identified potential commercial spin-offs as follows:

- Process Instrumentation

    - Furnace/Kiln Designs
        - laboratory and production types
        - modular systems
        - selection of refractories
        - insulation and electricals

    - Temperature/Process Controllers
        - electronics, hardware
        - programmable features
        - modular designs

    - High Temperature Viscosity Measurement
        - apparatus for glasses

- Piezoelectric Transducers for Laser Optics
    - Mirror/Fiberoptic Modulators
    - Micropositioners

The company also believes it has identified potential U.S. customers to whom it would provide hardware and services for advanced glass experiments on the T-33 aircraft.

AASTRA Aerospace Inc. has developed an automated apparatus for the T-33 designed to produce ceramic composites under microgravity conditions via the sol-gel method. The company has a request for licence in process with NRC.

AASTRA Aerospace Inc.'s sol-gel processing work has generated a technique for processing alumina which results in a high purity and high density material which is easily castable and shaped prior to sintering and requires a shorter sintering cycle and lower sintering temperatures. The company has in process with NRC a request for a patent on its sol-gel ceramics technology.

BTI's real-time dosimetry technology is leading edge when applied to measurements in space. General international agreements are in place with France and the USSR under which BTI delivers dosimeters for use in their respective space programs. This project has advanced the bubble technology, by supporting the development of detectors capable of differentiating between different types of radiation.

6.3 Opportunities

The bio-compatible materials being investigated by AASTRA Aerospace Inc. offer a potential market which can justify the high cost of space-based production.

Apart from any further developments in Canada, the following are candidates for use of the CAL furnace, or its components, in space programs: NASA; ESA; Japan; University of Florida; Clarkson University; Teledyne/South West Research Institute.

CAL's specific technologies, such as the ultrasonic measuring system and the video monitoring system may find application in terrestrial systems.

MPB believes it can fabricate high-quality custom substrates for growing ternary compounds for which there is a significant market. Ternaries cannot be fabricated using existing technology. Company capability will be a direct result of involvement with the LPEE process being investigated as part of the CHAMPS project.

The ThermaZone Engineering Inc. market study suggested there are terrestrial applications for the type of furnace Thermazone has designed. Sales of 50 units per year would make the product a commercial success. The company expects to distribute the furnace through the companies that are now servicing the research community.

7. CONCLUSIONS AND RECOMMENDATIONS

Our case studies reveal that the original objective of preparing industry for manufacturing on Space Station needs to be revisited. Initial utilization of Space Station will be driven by the scientific community, with industry supplying the supporting hardware. The hardware-oriented contractors have not demonstrated that they are users of microgravity. On the other hand, the smaller manufacturing companies we visited are using microgravity investigations to gain a better understanding of their terrestrial processes.

Conclusion and recommendations have been drawn from the findings in the case histories and are presented in reference to program administration and the published objectives of the UDP:

- commercial and economic opportunities;
- expansion of knowledge;
- development of hardware; and,
- provision of access to microgravity.

Each of the projects we reviewed achieved their agreed objectives. It is therefore possible to identify the factors that should be taken into account when assessing the probability of success for a particular project. We have also addressed the broader issue of whether the current practices of the program are the most effective in reaching the program objectives. As a general observation, we believe that the tax payer has received very good value for the resources expended. A small but active user community has been developed. Industry has been brought into the program and real commercial benefits are now being realized. Particularly significant has been the ability to introduce companies with manufacturing facilities to the opportunities for product and process improvement through experiments conducted in microgravity.

7.1 Commercial and Economic Opportunity Objective.

To identify promising areas of utilization of the space station environment with potential for eventual commercial and economic opportunities.

By the time the program had started, the USSR had performed many experiments in microgravity and it was believed the Space Shuttle combined with Space Station Freedom would provide the Western community with the facilities to carry out their investigations aboard their own vehicles. Availability of the Shuttle has fallen short of expectations, and Space Station is still over the horizon. The KC-135 offers short duration microgravity, useful for testing of equipment and hypotheses, but inadequate for commercial-scale processing.

It has become increasingly apparent around the world that commercial fabrication of materials in microgravity has not developed as expected. Vastly improved technology, based only on terrestrial developments, has been a significant contributing factor. At the same time, the challenges involved in developing equipment for microgravity have resulted in improved facilities for terrestrial applications. In these situations, there are prospects for hardware and services sales.

Where industry was the prime contractor, small entrepreneurial companies have been more successful than the larger ones in commercializing the results of their UDP contracts. The larger companies focused on providing hardware for use in microgravity, particularly on the Shuttle. The smaller companies used the experience with microgravity to improve their position in the terrestrial market place. The larger companies brought potential users into the projects. The smaller companies are users themselves, or worked jointly with other users, at the outset. This improves the likelihood that the development will meet real needs; the detailed, improved knowledge and capability resulting from working in microgravity find immediate application in an on-going manufacturing facility.

These conclusions lead to identification of the following key success factors in relation to achieving this objective:

- a clear definition of the requirement;
- the company had a technology before accepting a contract;
- an end-user was well-informed and an original participant in developing the proposal;
- availability of a good microgravity test bed;
- it was understood at the outset that the UDP would be used to improve terrestrial processes/products; and,
- for development of large-scale equipment, a company should have enough depth to be able to move people between divisions.

Recommendation 1. **When commercialization is the main objective, the UDP should concentrate its resources on small companies that can demonstrate their investigations in microgravity will lead to improved terrestrial processes or products, for example, companies with a manufacturing capability who can leverage the know-how acquired through the UDP involvement to improve terrestrial products or services.**

Recommendation 2. **The UDP should proceed with caution in the support of infrastructure hardware in cases where a need is not clearly identified by a user.**

7.2 Expand Knowledge Objective

To support studies and experiments to expand knowledge of relevant phenomena in the space environment and to demonstrate the possibilities of the proposed applications.

This objective is being met largely through contracts to university investigators. Some companies carry out investigations in microgravity with the express purpose of improving their terrestrially-based products. There is very little evidence at this time that manufacturing in microgravity will become a reality in the foreseeable future.

Access to microgravity is critical and experiments must be chosen carefully. Investigations requiring long duration in microgravity, days for instance, are suffering from lack of availability of accommodation in the Shuttle or other vehicles. Space qualification is also time-consuming. One post-doctoral student works full-time on paper-work for an experiment to be flown in IML-1. In short, it is difficult to assign Ph.D. candidates to projects involving microgravity when the time- frame is many years. Preliminary experiments can be performed in the KC-135 or T-33. Cooperation with willing co-investigators from US institutions who have easier access to the Shuttle facilities offers a further possibility.

University projects play a critical role in developing scientists and engineers who understand the requirements associated with working in space. Canada will need people with this background if we are to continue successfully in space programs.

Key success factors in meeting this objective are that:

- the problem is well defined;
- the Scientific Authority has the ability to judge the project scientifically;
- exceptionally good shop facilities are available to support the project; and,
- space qualification is undertaken by industry, leaving the university free to do research.

Recommendation 3. **In the light of experience to date, the UDP should focus its main effort in regard to expending knowledge on university-based projects that lead to the award of an M.Sc. or Ph.D.**

The delays inherent in a microgravity program suggest that a university PI cannot afford to spend all his or her research time on investigations requiring this environment. This may be one factor that inhibits some of the best scientists from turning their attention to microgravity.

The UDP organizes an annual conference at which PI's report on their experimental results. This is a very important activity to keep the participating community well informed. It does not, however, reach non-participants, particularly those PI's who are leaders in their fields but have eschewed working in microgravity. The UDP should take steps to change this situation and to attract the best researchers to the program.

Recommendation 4. **The UDP should consider holding a workshop to bring together the PI's who are working in microgravity with the leading PI's in the same field. This could be run as an independent workshop, or arrangements could be made with a national scientific society to devote one session at its annual conference to reports on microgravity investigations.**

7.3 Development of Hardware Objective

To assist in the definition and development of hardware for eventual use on the Space Station.

At the time the UDP began, this was a worthy and necessary objective. The requirements for space-qualified equipment such as furnaces were not widely known or understood by investigators or fabricators. Canada has had a strong space industry for decades. Members of that community are well informed and capable. New entries in the field wishing to work in materials processing in microgravity are rather less so.

Companies experienced in space were quick to offer services providing furnaces or similar infrastructure. The user community was not as extensive or as experienced. This gap was closed to some extent by searching out users for the hardware. However, the original concept of hardware for Space Station has faded as the latter's availability, and perhaps suitability, recedes into the future. Problems with the Shuttle are resulting in fewer-than-hoped-for opportunities to carry out experiments in its lockers.

Given the adverse circumstances encountered in using the Shuttle, the UDP has been successful in providing the hardware infrastructure it set out to develop. The key success factors which have led to successful hardware development are:

- existence and maintenance of a good technical team in industry;
- a Scientific Authority or Contract Manager who knows what is wanted;
- permitting the company to decide how to proceed;
- a company that pays attention to comments at review meetings; and,
- good customer relations.

The following is a list of hardware available or under development for microgravity experiments.

Hardware Under Development

1. QUESTS Gradient Furnace (Queen's University)
2. QUESTS Isothermal Furnace (Queen's University)
3. Rapid-Quench KC-135 Furnace (Queen's University)
4. GEODE Gradient Furnace (Electrofuel Manufacturing/SED Systems)
5. Heat-Pipe Isothermal Furnace (Electrofuel Manufacturing)
6. Multi-Chamber Isothermal Furnace (Electrofuel Manufacturing)
7. ThermaZone Gradient Freeze Furnace
8. Float Zone Furnace (Canadian Astronautics Ltd.)
9. Glass Processing Furnace for KC-135 Aircraft (B.M. Hi-Tech)
10. Glass Processing Furnace for T-33 (B.M. Hi-Tech)
11. Aerodynamic Levitator and Heating Facility (B.M. Hi-Tech)
12. Drop Injector (Canadian Astronautics Ltd.)
13. CHAMPS Modular Get-Away-Special Payload (MPB Technologies Inc.)
14. Automated Multipurpose Heating and Rapid-Cooling Facility (McMaster University)
15. Data Acquisition System for KC-135 (NRC)
16. Rapid Solidification Furnace System (ORTECH)
17. KC-135 Accelerometer Unit (CSA)
18. Large Motion Isolation Mount for the KC-135 (CSA, UBC)
19. Infrared Data Technology System (CSA, SFU)
20. Functional T-33 Flight Hardware for Sol-gel Processing of Advanced Ceramics (AASTRA)*

* Case history.
Source: Microgravity Program Update, Number 4, May, 1990.

Recommendation 5. **In the near term, the UDP should be wary of supporting the development of hardware which can only be used in the Shuttle or on Space Station.**

We are unsure of the strategy being pursued by the UDP to make good use of the hardware infrastructure it has developed. We think this should be addressed.

Recommendation 6. **The UDP should develop a strategy for encouraging the use of hardware developed by the program.**

7.4 Providing Access to Microgravity Objective

To provide opportunities to access the microgravity environment on a regular basis, including the use of microgravity aircraft, rockets and other spacecraft.

We have referred to the changing expectations as a result of the Shuttle problems. The UDP has kept the user community involved by arranging for accommodation on the KC-135, and also by providing a T-33 converted for short-duration, small-sized experiments. The latter is under direct Canadian control and thus not subject to competing demands from other national interests. Cost is a factor. And the T-33 is very attractive for companies who fund their own space flights. The Falcon-20 will be a welcome addition to the Canadian capability.

International cooperation is also attractive. Program management has sought out opportunities for cooperation with space agencies in other countries involving rockets, satellites and space laboratories. These actions have resulted in access to microgravity that would have been impossible otherwise, and have contributed to the maintenance of the Canadian space program, at least as far as a user community is concerned.

The UDP has made extensive use of the various vehicles available for microgravity experiments. A summary of the flights arranged is presented below.

Number of Experiments Completed and Planned

Vehicle	Date	Materials	Life Science	Education
KC-135	Feb/87	2	4	0
	Oct/87	3	3	1
	Mar/88	4	5	0
	June/88	0	1	1
	Oct/88	3	7	2
	Mar/89	9	3	1
	June/90	0	3	0
	Feb/90	9	9	0
T-33	1989	3	3	0
Rocket	1987	2	0	0
Rocket	1991	5	0	0
GAS Payloads		3	0	1
Shuttle Mid-Deck Locker		1	7	0
IML-1	1991	0	6	0
IML-2	1993	1	2	0
Spacelab-J	1991	0	1	0
Biocosmos	1989	1	5	0
	1992	1	3	0
	Total	47	62	6

Source: Microgravity Updates 1-4.

The variety of vehicles used by the UDP is testimony to the success in providing the essential access to microgravity. A key success factor in meeting the objective is:

- innovative management that takes the time and applies the resources to search out all opportunities to accommodate microgravity experiments.

Recommendation 7. **Program management should continue to explore and pursue all available opportunities for access to microgravity.**

7.5 Program Administration.

We have made several references above to matters that fall within the rubric of program administration. We should report here that we received only the highest praise for the way in which the program is managed. This is not to imply that there is no room for improvement. But given the complexities and uncertainties, the program is being well administered.

Contractors must meet payrolls. In circumstances where projects are being phased, delays between phases result in reassignment of personnel, idle personnel or lay-offs. None of these options is conducive to the maintenance of a project team, or the efficient prosecution of a project. This leads to the following recommendation.

Recommendation 8. **Every effort should be made to reduce the "dead time" between successive phases of a project.**

Two issues arise when a project reaches the stage where it should proceed to microgravity. The first relates to the timing associated with Announcements of Opportunity. We recognize that Canadian use of the KC-135 and Shuttle is controlled elsewhere, and that opportunities for Canadian experiments may be made available on short notice. This puts stress on the system for selecting the best experiments and the time for preparation. We believe that the UDP should address this matter.

Recommendation 9. **The UDP should apply its best effort to obtaining a lead time of one and one half years for each Announcement of Opportunity.**

The second issue is paper work. We have been told that one experiment in IML-1 requires 650 written reports. While the NASA authority has some discretion regarding the number of written reports required, nevertheless the paper work is clearly burdensome. The PI must be involved, as he or she is the only one who can provide information on the experiment. The sheer volume governs the time involved, which extends over months. This is very difficult for PI's, who are neither accustomed to, nor set up for, this undertaking. While we know this situation is recognized by the Canadian Astronaut Program Office (CAPO), nevertheless we believe that an effort should be made to reduce the demands on PI's. Failure to do so could eventually lead to withdrawal from, or unwillingness to participate in, microgravity studies.

Recommendation 10. **The UDP, in conjunction with CAPO, should examine the reporting requirements for space experiments with the aim of reducing the paper work-load on PI's.**

7.5.1 Space Sciences Program

During our study, we noted the existence of several committees established to provide advice to the Space Science Program. These committees are:

1. Canadian Advisory Committee for the Scientific Utilization of Space Station (CACSUSS);
2. Life Sciences Advisory Committee;
3. Material Sciences Advisory Committee;
4. Joint Subcommittee on Space Astronomy; and,
5. Solar Terrestrial Relations Advisory Committee.

The first three committees are directly concerned with activities that fall within the purview of the UDP. CACSUSS is an umbrella committee with the important function of acting as the counterpart to the equivalent committees established by the international partners in Space Station. It also has a role in advising on Space Science programs as they relate to Space Station.

The second two committees deal with the Space Science programs in life sciences and material sciences. They are expected to act as the interface between the program and the scientific community.

Conflict of interest and dissemination of proprietary information has placed restraints on these committees to review proposals, particularly those from industry which may contain industrially confidential information. This is unfortunate, since these committees include in their memberships the very experts who could be most valuable in assisting UDP management in selecting the most appropriate proposals.

The situation can be tackled in two ways. First, the RFP can specify that the committees will assist with the evaluation. Second, each member can be asked to sign a confidentiality agreement. This latter process should satisfy industrial requirements at the proposal stage. Because the advice of the committees can be so useful, we believe they should be involved in the early evaluation of all proposals.

It has been the practice to use individual outside reviewers. Confidentiality agreements have been signed to protect proprietary interests. While this process works well for review of papers submitted to scientific and technical journals, we believe the discussion that takes place in a committee is more appropriate when dealing with proposals leading to contracts which form part of a defined program.

Recommendation 11. **Program management should determine the most appropriate course of action that will permit the advisory committees to be involved in the evaluation of all proposals for the UDP. When a suitable process has been identified, it should be implemented.**

7.5.2 Canadian Astronaut Program Office

The mandate of the Canadian Astronaut Program Office is as follows:

- encourage and support the development and execution of Canadian scientific and technical programs in space;
- support the Space Station Program Office throughout all phases of the Mobile Servicing System (MSS) project;
- participate in the utilization of the international space station's resources and provide space station crew members as required;
- promote public awareness of Canadian space science and technology; and,
- encourage young people to pursue careers in science and technology.

The CAPO office provides financial support for some experiments in microgravity. Some members of CAPO act as scientific advisors for UDP projects.

Members of the CAPO are enthusiastic and dynamic proponents for, and participants in, microgravity projects. In most circumstances the astronauts will be called upon to perform the experiments designed by other PI's. It is therefore axiomatic they be closely involved with the microgravity experiments.

The astronauts recognize that requirement, and are participating with PI's in the design of experiments. As noted previously, each KC-135 and some T-33 experiments involve an astronaut. This close working relationship should be encouraged. One way is to include astronauts in the project selection process. We therefore offer the following recommendation.

Recommendation 12. **An astronaut should be included in the membership of the Space Sciences Advisory Committees that are involved in evaluating proposals to the UDP.**

The assignment we have carried out has provided historical information. Our findings suggest that it is appropriate to focus attention on the strategy for the future. As originally conceived, the purpose of the UDP was to prepare industry for the availability of platforms in microgravity. As discussed above, high expectations have been reduced in terms of manufacturing in space. The program is therefore shifting to the support of industries which can make use of experiments in microgravity to improve terrestrial processes, and to universities where microgravity provides a new laboratory. We believe this to be the correct approach.

Industry does not seem to encounter difficulties in gaining access to information regarding RFP's or to dealing with the required paper-work. RFP's distributed to the university community often go to the administration office, where they may or may not reach an appropriate PI. Furthermore, university PI's are unaccustomed to the SSC documentation, which if not understood can discourage participation in the program.

This concern leads to the question of the size of the university community from which potential participants can be drawn, and whether there is a more effective way of gaining their participation. Furthermore, if there were a rush of good proposals, are there sufficient funds in the program to maintain interest until the Shuttle and Space Station are available.

These matters can be addressed in a strategic plan, and can only be satisfactorily dealt with through the process of developing the strategic plan.

Recommendation 13. **The UDP should develop a strategic plan that takes account of the prospects for access to microgravity, the best use that can be made of the microgravity platforms, and the most effective process for ensuring that the best investigators have an opportunity to participate in the program.**

8. ACKNOWLEDGEMENTS

We wish to acknowledge the support willingly given by all participating contractors and their subcontractors. UDP management has been helpful and available for consultation as required. CAPO and members of the Space Sciences Division also provided valuable insights.

Appendix I

Case History

AASTRA Aerospace Inc.

A Study for the Development of Ceramics Processing in Space

AASTRA Aerospace Inc.
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Downsview, Ontario
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Case Study

1.0 BACKGROUND

1.1 Company Profile

AASTRA Aerospace Inc. is based in Toronto and operates as a subsidiary of a private holding company, AASTRA Corporation, controlled by Dr. Francis Shen and Hugh Sclolaert, who are both active in AASTRA Aerospace. AASTRA Aerospace employs fifteen people, twelve of whom are engineers with post graduate degrees.

AASTRA Aerospace Inc. was created in 1983 when Francis Shen and Hugh Scholaert acquired H. AASS Aero Engineering Ltd., a company which had been incorporated in 1970. At the time of the acquisition, the company employed two engineers and a draftsman and was engaged largely in providing aeronautical engineering services for the implementation of surveys, surveillance and R&D on aircraft. Shen and Scholaert wanted to move the company into more technically intensive projects by offering systems engineering services to the aerospace and defence markets.

In 1988, AASTRA acquired financially-troubled ALMAX Industries Ltd. in Lindsey, Ontario, a manufacturer of advanced ceramics, and renamed the company AASTRA Advanced Ceramics. AASTRA Aerospace had teamed with ALMAX as subcontractor for its first UDP contract (Phase I, January to July 1987). AASTRA Advanced Ceramics employs seventy people in a 30,000 square foot facility which manufactures advanced ceramic components for ultrasonic transducers used in sonar and medical imaging devices. The plant is one of the largest of its kind in North America. Most of the plant's ceramic production is exported to the United States, largely to the U.S. Navy.

AASTRA considers B.M. Hi-Tech to be a "small" competitor.

1.2 Microgravity Connection

AASTRA decided in 1986 that it wanted to get involved in technology development for space. The UDP offered an opportunity to do this. The company identified advanced ceramics as an area which might benefit from microgravity processing, but it lacked the expertise to pursue the opportunity. Consequently, the company decided to team with ALMAX Industries, an advanced ceramics manufacturer in Lindsey, Ontario, and landed its first UDP contract (Phase I, $87,613) in 1986. AASTRA acquired financially-troubled ALMAX in 1988 and renamed the company AASTRA Advanced Ceramics.

As a result of its ceramics work under the UDP, AASTRA developed expertise which positioned the company to become involved in the study of protein crystallization in microgravity. The company has had two UDP contracts in this area, Phase I in 1988 valued at $87,671 and Phase II in 1990 valued at $80,022.

1.3 Microgravity Expectations

High performance ceramics are currently characterized by an inability to reliably produce and cost-effectively manufacture materials with the desired properties and microstructure. The company anticipates that the study of advanced ceramics processing in microgravity will strengthen its understanding of processing parameters on earth by eliminating the gravity factor. This is expected to enhance the ability to produce materials with improved properties, for example, bio-materials for use in bone implants, a large and lucrative market.

2.0 PROJECT DESCRIPTION

This work is part of a five-phase program proposed by AASTRA to develop products and processes capable of exploiting a microgravity environment. The purpose of advanced ceramics research is to develop better materials for high strength and severe environment applications. AASTRA's approach to this work involves ceramic matrix/ceramic inclusion composites, in which an attempt is made to increase the strength and toughness of a ceramic with the addition of a second toughening phase. A major challenge with this approach is the current inability to achieve random homogeneous distribution of the inclusion phase. The inclusion phase separates from the matrix because of density and/or flow property differences between it and the matrix. Phase separation causes second phase agglomeration, resulting in stress concentration rather than toughening. Gravity is the sole contributing factor to phase separation. It is anticipated that microgravity would improve second phase distribution. Increased homogeneity results in superior ceramic properties with greater mechanical reliability.

2.1 Objective

This work has to date involved three phases.

Phase I, completed in July 1987 with ALMAX Industries as subcontractor, had the following objectives:

- to identify advanced ceramics for which microgravity processing appeared economically justified; and,
- to identify processes for advanced ceramics production which would benefit from microgravity.

Phase II, completed in January 1989 with ALMAX Industries as subcontractor, had the following objectives:

- to develop processing hardware for T-33 experiments; and,
- to perform exploratory experiments in ceramic compositing.

Phase IIb, scheduled for completion in December 1990, has two objectives:

- to continue the work on sol-gel processing of alumina/silicon carbide and alumina/zirconia composites initiated in Phase II. Although the analysis of some of the samples flown showed promising results, these are still preliminary; and,
- to explore the advantages of microgravity processing of bio-ceramics, focusing on a new porous zirconia aerogel for bone implants. Ground-based experiments will be performed to characterize the system for microgravity flights and to provide control data. Up to four flights will be flown to provide samples for analysis. Microgravity experiments will be performed in existing apparatus.

2.2 Methodology

Work to date has involved identifying a market (bio-materials) and a process (sol-gel), followed by T-33 airborne experiments using baseline ceramic composites which are currently produced on earth. Experimental investigations emphasize controlling the parameters.

2.3 Schedule and Budget

The phasing and funding have been as follows:

Phase	Start	End	Cost
I	Jan. 1987	Jul. 1987	$ 87,613
II	Jan. 1988	Jan. 1989	$ 152,500
IIb	Sept.1989	Dec. 1990	$ 156,503

3.0 RESULTS

After a review of technical and economic issues, Phase I identified and recommended for further study:

- bio-active glass composites (applicable, for example, to artificial replacement joints); and,
- liquid-phase ceramic powder production, whose advantages include control of particle size and a high degree of purity in the final product.

In Phase II, the company decided to concentrate on sol-gel processing of two materials:

- silicon carbide reinforced alumina; and,
- zirconia toughened alumina.

Ground-based experiments were performed, an apparatus was developed for T-33 experiments and sol-gel processing experiments were flown on the T-33 aircraft.

3.1 Degree of Success

Work to date has:

- developed functional T-33 flight hardware for sol-gel processing of advanced ceramics;
- developed sol-gel processes for silicon carbide reinforced alumina and zirconia toughened alumina; and,
- demonstrated differences in distribution of second phase material between ceramic composites processed in microgravity versus those processed on earth.

3.2 Problems Encountered

Microgravity experiments for the company's sol-gel processing investigations have been designed around the T-33 aircraft, which provides microgravity durations of only 15 to 20 seconds. This has required the use of a gelling agent which generates a large amount of water. Consequently, periods of up to two months are necessary to dry these samples and the drying process often leads to cracking of the gels. With respect to zirconia gels, it has to date proven impossible to create a solid sample, with powders resulting upon drying. The company feels that access to longer duration microgravity experiments will be necessary (for example, on the shuttle) in order to produce more monolithic ceramics.

3.3 Expectations Met

The company has achieved all of the objectives as identified in various phases on time and on budget. The problems identified in section 3.2 above have occurred in Phase IIb, which is scheduled for completion in December 1990.

3.4 Benefits

Phase I and its economic analysis convinced AASTRA that it was worthwhile to get into the manufacture of advanced ceramics and led directly to its acquisition and turn-around of financially-troubled ALMAX in 1988.

The UDP has helped to position the company with respect to what it feels are significant potential commercial opportunities in the field of advanced ceramics, particularly in the bio-materials market for products such as bone implants.

The company's involvement in UDP advanced ceramics work put AASTRA in a position to successfully pursue UDP protein crystallization work. This work in turn exposed the company to dynamic light scattering technology, which is applicable to the analysis of ceramic powders and may enhance quality and processing control by enhancing the ability to identify particle size distribution.

The company feels that its UDP involvement has allowed it to employ materials researchers to study advanced processing concepts and to develop a strong engineering team capable of providing engineering services in hardware development for space applications.

3.5 Spin-offs

AASTRA has developed an automated apparatus for the T-33 designed to produce ceramic composites under microgravity conditions via the sol-gel method. The company has a request for licence in process with NRC.

AASTRA's sol-gel processing work has generated a technique for processing alumina which results in a high purity and high density material which is easily castable and shaped prior to sintering and requires a shorter sintering cycle and lower sintering temperatures. The company has in process with NRC a request for a patent on its sol-gel ceramics technology.

3.6 Client Interactions

The company expressed the view that the UDP is understaffed and that staff are "juggling too many proposals and projects". It is felt that this results in delays between projects and impacts negatively upon the timeliness and frequency of feedback on proposals and final reports.

4.0 CONCLUSIONS

4.1 Strengths

- The UDP has nurtured rather than directed industry proposals. Therefore, it is more likely to use Canadian industrial strengths and more likely to result in spin-off.

- As a participant in the UDP, AASTRA offers good potential for spin-off because its manufacturing capability puts it in a position to leverage advanced ceramics technology developed under the UDP.

4.2 Weaknesses

- Flight opportunities are extremely limited and of short duration, requiring that experiments be extremely well thought out.

- The UDP is overly focused on hardware development which will be obsolete in the near future as flight opportunities change. The focus should be on process research.

4.3 Success Factors

- Availability of increased microgravity time to researchers. The expanded capability represented by T-33 flights has the limitation that it provides only 15 to 20 seconds of microgravity. The company feels that access to longer duration flights in the near future is vital to its work.

4.4 Opportunities

- Making bio-compatible material offers a potential market which can justify the high cost of space-based production.

4.5 Administration

- Given the staffing level and the number and scope of projects, the company feels that the UDP is extremely well administered.

- The company expressed some concern with respect to the stability of the UDP in light of the impending move of the CSA to Montreal.

5.0 OBSERVATIONS

In our judgement, AASTRA is a well-organized, very professional, market and strategically oriented company. It is a good fit with both the industrial benefit and acquisition of new knowledge objectives of the UDP.

6.0 PERSONS CONTACTED

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Appendix II

Case History

B.M. High-Tech Inc.

Microgravity Processing of Materials for Infrared Optics and Sensors: Development of a Research Program

B.M. Hi-Tech Inc.
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Case Study

1.0 BACKGROUND

1.1 Company Profile

In May 1983, Blue Mountain Pottery, a large and successful giftware business in Collingwood, Ontario, created a new subsidiary called B.M. Hi-Tech Inc. to pursue opportunities in the advanced ceramics and piezoelectrics industry. Dr. Eswar Prasad was hired to lead this effort. In 1985, four employees, including Dr. Prasad, bought B.M. Hi-Tech through a holding company called Sensor Technology Limited. Initially, the company operated as a research organization; building on its research and development base, it moved into production in 1987 with a contract for the United States Navy.

B.M. Hi-Tech is positioned as a small, entrepreneurial, niche-oriented company with a strong export orientation. The company currently markets a range of piezoelectric ceramics, glasses, composites, transducers and acoustic systems for various end users in Canada, the United States and Europe for applications which include sonar, medical imaging, power ultrasound, aerospace and communications.

The company is based in Collingwood, Ontario where it maintains a 7,500 square foot facility. B.M. Hi-Tech employs 15 people, including one person attached to the University of British Columbia in Vancouver and two people in Ottawa. Company sales are in the $500,000 to $700,000 range. The company reports that 15% of its revenues currently come from UDP, compared with 80% in 1986.

1.2 Microgravity Connection

B. M. Hi-Tech's participation in microgravity research began in 1984 and predates the UDP. Under the Space Station Industry Joint Endeavour Program from November 1984 to March 1985, the company generated a detailed study on the processing of glasses and ceramics in microgravity which identified areas of commercial potential and required experimental work. The study also addressed the limitations and physical constraints of microgravity processing.

1.3 Microgravity Expectations

In the past decade, materials limitations have become an important constraint in the development of sophisticated hardware for medical, communications and industrial process and control devices, to mention just a few examples. In many applications, advanced glasses and ceramics are the only candidate materials considered likely to be capable of performing the desired function.

Materials limitations provide an important impetus for investigating the processing of glasses, ceramics and composites in microgravity. Materials processing in low gravity environments eliminates the undesirable effects of sedimentation, buoyancy, hydrostatic pressure and convection on the quality of the processed products such as advanced optical glasses, ceramics, metals, fluids and cells, resulting in unique, higher quality products and purer materials. Promising applications for microgravity-processed materials include infrared optics and sensors.

Experimentation in microgravity is expected to provide an improved understanding of the science and basic parameters of making advanced glasses, thereby providing an opportunity to develop or perfect earth-based technology. Specifically, a better understanding of phenomenological properties (such as nucleation and crystallization) and processing technology (such as homogenization and high purity processing) are anticipated.

2.0 PROJECT DESCRIPTION

The overall objective of B.M. Hi-Tech's UDP work is to explore microgravity processing of glasses for infrared optics and sensors, with a view to developing a range of fluorozirconate glasses that can be used for various electro-optical devices, including low-loss fibre optics.

2.1 Objective

This work has to date involved five phases.

The objective of Phase I, a Preliminary Definition Phase completed in March 1986, was to develop a range of fluorozirconate glasses and evaluate their properties.

The objective of Phase II was to establish glass formation regions in the materials identified in Phase I and to evaluate systematically their compositions and characteristics, with a view to producing these glasses in microgravity. This phase also included work to develop a levitator for containerless processing in one-g to identify further appropriate materials for study in microgravity.

The objective of Phase III was to perform additional experimental work to improve the quality of glass materials through control of crystallization and purity of starting materials. This phase also included further design work on the aerodynamic levitator and glass processing experiments using the KC-135 and T-33 aircrafts.

The objective of Phase IV was microgravity investigation of the kinetics of phase separation and crystallization of fluorozirconate glasses. This included completion of an automated glass processing furnace for low-gravity experiments on the T-33. Technology was to be developed to purify raw materials to facilitate the production of glasses with lower transmission losses. In addition, preliminary design work on a glass fibre drawing system and process hardware for a rocket experiment was to be carried out.

Phase V began in August 1990. This phase has three objectives. The first objective is to study the phenomenon of phase separation and crystallization in fluorozirconate glasses using ground-based and microgravity experiments on the T-33 facility. The aim is to establish optimized conditions for heat treatment of these glasses to eliminate or minimize phase separation and crystallization in the fibres during fibre pulling. The second objective is to develop hardware for the rocket payload and deliver the payload for integration and launch in 1991 for use in long duration microgravity experiments to gather conclusive evidence of the benefits of microgravity materials processing. The third objective is to carry out fibre pulling and characterization experiments with the aim of comparing the properties of the fibres with those of the preforms in an attempt to optimize various process parameters. Phase V will be completed in July 1991.

2.2 Methodology

This program's methodology involved:

- the development of chemical compositions, materials and processing technologies;
- the design and development of hardware, including payloads for KC-135, T-33 and rocket payloads, as well as an aerodynamic levitator;
- zero, one and two g experiments to determine the effects of three gravity reference points;
- modifying materials, processing techniques and hardware based on experiment results; and,
- identifying markets and spin-offs for the capability which has been generated.

2.3 Schedule and Budget

The phasing and funding have been as follows:

Phase	Start	End	Cost
I	Jun. 1985	Mar. 1986	Pre UDP
II	Oct. 1986	Mar. 1988	$443,307
III	May 1988	Mar. 1989	$399,364
IV	Aug. 1989	Jun. 1990	$271,210
V	Aug. 1990	Jul. 1991	$262,142

Phase III and V involve significant sub-contracting.

3.0 RESULTS

Phase I indicated that useful components could be developed for various electro-optical devices.

Phase II systematically investigated the glass-forming region of the fluorozirconate system and characterized the glasses. Preliminary design work was done on a new type of aerodynamic levitator with infra-red heaters capable of containerless processing in one-g to identify further the appropriate materials for study in microgravity. In addition, a glass processing furnace was developed for use on the KC-135. The furnace is capable of heating small samples to temperatures of 1000 degrees C, then quenching them in a short period of time.

Phase III involved additional ground-based experimental work to improve the quality of the glass materials through control of crystallization and purity of starting materials. Further design work was completed on the aerodynamic levitator. A glass processing experiment was flown on the KC-135 aircraft in October 1988, and an automated furnace system was developed for an experiment which was flown on the T-33 aircraft in March 1989.

During Phase IV fluorozirconate glasses for optical components, fibre preforms and specimens for microgravity investigations were generated. Hardware and modifications for T-33 payloads were made. Microgravity investigations on ternary and fluorozirconate glasses were carried out. Preliminary design work on a ternary glass fibre pulling system was completed, as was preliminary design work on a rocket-borne experimental payload.

3.1 Degree of Success

During the first four phases, a range of glasses based on a fluorozirconate system has been developed and their properties evaluated. The results indicate that useful device components can be developed from these glasses for various end users. The results further indicate that other useful properties, such as ionic conductivity, exist in such materials. B. M. Hi-Tech introduced some of these compositions into its product line in 1990. Glass processing furnaces have been developed for microgravity experimental work on T-33 and KC-135 facilities, as has a ground-based aerodynamic levitator system for containerless processing of materials. Preliminary design work on rocket-borne payload and fibre optic systems has been completed. Experimental investigations on the kinetics of crystallization and phase separation in ternary glasses have been carried out.

3.2 Problems Encountered

The company was frustrated by limited space on KC-135 flights, clearing equipment through U.S. customs and the expense involved in sending personnel to Houston. The availability of T-33 flights has eased these problems.

The extensive safety reviews necessary for flights, while understandable and necessary, proved to be time-consuming.

The company expressed concern that UDP funding for its aerodynamic levitator has been terminated.

The company takes the position that it is difficult to buy reliable, off-the-shelf hardware for scientific and applications purposes. It has had to develop, test and de-bug its own hardware for use on KC-135 and T-33 flights.

The company notes that it does not have the resources to be both a strong scientific as well as a successful commercial organization.

Early in the company's involvement in the UDP, when UDP funding represented a large part of the company's revenue, funding delays created serious problems.

3.3 Expectations Met

As evidenced by repeat funding, B.M. Hi-Tech has a good track record with respect to the successful completion of complex projects. The objectives as set out above were met within the time and budget allowed.

3.4 Benefits

The UDP has been instrumental in supporting and nurturing a small, entrepreneurial Canadian company. B. M. Hi-Tech has evolved from a fledgling company with little microgravity know-how into an organization with capability and expertise in advanced glasses, one of a small number of world manufacturers of fluoride glasses. The company's capability has evolved to include:

- integrated facilities and expertise at one location for the production of glasses, ceramics and transducers;
- competence to develop new materials, incorporate them into components and devices and identify practical production techniques;
- expertise in the design and support of complex process hardware and related automation;
- the ability to market its products and services domestically and abroad; and,
- a strong world-wide network of contacts in advanced ceramics and glasses and related disciplines.

3.5 Spin-Offs

B.M. Hi-Tech has developed three pieces of hardware under this program. The first is a manual glass processing furnace for KC-135 aircraft which heats small samples to temperatures up to 1000 degrees C, and allows quenching of samples in a short period of time. This furnace is operational and is available for use by others. B.M. Hi-Tech also developed a second, automated furnace for glass processing for T-33 aircraft use. This unit features a triple containment system to heat small samples to temperatures up to 1000 degrees C, and also allows quenching in a short period of time. This hardware flew on the T-33 in March 1990 and is operational. Third, B.M. Hi-Tech developed an aerodynamic levitator and heating facility. This unit is a ground-based levitator with infra-red heaters designed for containerless processing to temperatures up to 1200 to 1500 degrees C. A prototype is complete and the company has a request for licence in process with NRC. UDP funding for the aerodynamic levitator has been terminated.

The company has identified potential commercial spin-offs as follows:

- Process Instrumentation
  - Furnace/Kiln Designs
    - laboratory and production types
    - modular systems
    - selection of refractories
    - insulation and electricals

    - Temperature/Process Controllers
        - electronics, hardware
        - programable features
        - modular designs

    - High Temperature Viscosity Measurement
        - apparatus for glasses

- Piezoelectric Transducers for Laser Optics

    - Mirror/Fiberoptic Modulators

    - Micropositioners

The company also believes it has identified potential U.S. customers to whom it would provide hardware and services for advanced glass experiments on the T-33 aircraft.

3.6 Client Interactions

Client interactions have been good.

4.0 CONCLUSIONS

4.1 Strengths

- Initial willingness to fund a small company with limited experience in microgravity, but with good ideas and people.

- Subsequent funding based on project track record.

4.2 Weaknesses

- The logistics and costs associated with U.S.-based microgravity flights are problematic, especially for small companies. The availability of Canadian-based rocket and T-33 flights has ameliorated this problem.

- The UDP is seen to be ambivalent with respect to the appropriate balance and relationship between scientific investigation and the development of products and services with potential commercial applications. The company feels that it does not have the resources to be <u>both</u> a strong scientific as well as a successful commercial organization.

- The company takes the position that it is difficult to buy reliable, off-the-shelf hardware for scientific and applications purposes. It has had to develop, test and de-bug its own hardware for use on KC-135 and T-33 flights. The company has also expressed dismay that UDP funding for its aerodynamic levitator has been terminated. The UDP seems to be ambivalent with respect to this issue.

4.3 Success Factors

- Willingness to fund a small company with good ideas and people and to judge it on its subsequent track record.
- Funding of an organization which can translate scientific research into a pragmatic, creative and entrepreneurial approach to competing in world markets.
- Funding continuity to maintain in tact a good technical team.
- A balance between careful monitoring and an arms length approach.
- The availability of good microgravity test beds such as the KC-135 and T-33.
- Experiments need to recognize the constraints of zero gravity and include one and two g reference points.
- Resolution of the apparent ambivalence in the UDP with respect to the relative emphasis on science and applications.
- Clarification with respect to the role of the UDP in funding the development of hardware.

4.4 Administration

Early in the company's involvement in the UDP, when UDP funding represented a large part of the company's revenue, funding delays created serious problems.

5.0 OBSERVATIONS

B.M. Hi-Tech is an extremely pragmatic and entrepreneurial company with a strong market orientation. It has benefited substantially from participation in the UDP.

6.0 PERSONS CONTACTED

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Appendix III

Case History

Bubble Technology Industries

To Study the Feasibility of Using Bubble Detectors for Dosimetry Applications in Space.

Bubble Technology Industries
Highway 17
Chalk River, Ontario
K0J 1J0

Case Study

1.0 BACKGROUND

1.1 Company Profile

Bubble Technology Industries (BTI) was formed in 1988 as a spin-off from the Chalk River Laboratories of Atomic Energy of Canada Ltd. (AECL). Its products are a line of radiation detectors based on a new technology. The company is R and D intensive, with 5 Ph.D.'s in a staff of 15. Sales account for about 30% of the company revenue, the rest coming from R and D contracts. Support comes largely from the military in Canada and the USA. There is an intense effort to develop other markets.

The technology is known as "Bubble Technology", and involves the use of microscopic droplets of a metastable liquid dispersed in an elastic polymer. These droplets vaporize when struck by radiation, forming a visible bubble in the polymer. The bubbles are counted after exposure, and the number is a measure of the radiation dose to which the detector has been exposed. By altering the composition of the droplets, detectors can be made that selectively respond to different radiations, and for a given radiation, can respond to an energy range.

The detector is small, test-tube in shape, with dimensions of 3" in length by .5 inch in diameter. It is easily portable, and finds applications where radiation monitoring is required. The detector technology was originally developed for use in the nuclear industry. One important aspect of the detector is that it gives an immediate, visible, response to exposure to radiation. No further processing is required.

Detectors are calibrated using standard sources, and in this way the number of bubbles can be related to radiation dose. While the detector gives an immediate indication of exposure, a quantitative measure of dose requires a bubble count. BTI has developed a number of techniques for this purpose, ranging from manual counting to automated counting with computer analysis.

While the technology is mature for general radiation detection, research and development are continuing to refine the selectivity and increase the capability to detect a wider range of particles. One recent innovation has resulted in a rechargeable detector that can be used repeatably. In the absence of the recharging technology, once a detector became "saturated" with bubbles it was discarded.

Proprietary aspects relate to the composition of the droplet materials, their fabrication, and the technique for their dispersal in the polymer. These are protected by patents taken out when the technology was developed and held by AECL. BTI operates with a royalty agreement with AECL.

The first commercial interest in the detectors came from the US navy. This led to interest from other parts of the US military, US government departments, and NASA. A major, but not sole, interest is in the health field. NASA showed interest in pursuing development of bubble detectors, but BTI found the contractual process with NASA to be too closely geared to procurement of large hardware, and too cumbersome for a company such as BTI. This potential client is therefore not being pursued at present.

1.2 Microgravity Connection

The starting point in the trail leading to the involvement of BTI in the User Development Program (UDP) was the decision of AECL to seek commercial applications for technologies developed in its research laboratories. During this process, representatives contacted groups within what was then the National Research Council of Canada (NRCC), now the Canadian Space Agency (CSA), to assess what opportunities there might be in the space program for AECL technology.

As a result of this initial contact, three members of the space program visited Chalk River and made presentations on the approach of the space program to commercialization, the robotics aspects of the program, and the program for the development of Canadian capability to use microgravity. The already identified concern regarding the exposure of astronauts (and satellites) to the intense radiations of space, led to a natural interest in the potential application of bubble technology to the space environment. The combination of a new technology with a potential need resulted in the contractual undertakings agreed to between the supplier, which emerged as BTI, and the UDP.

BTI has been direct involved with space programs in other countries. A French cosmonaut flying with the USSR MIR program carried a BTI detector. The experience with that detector has led to an agreement between France and Canada to support the development of bubble detectors for space. The USSR space program has also shown interest in the technology, and have made some attempts, believed to be unsuccessful, to duplicate the bubble technology.

The decision to proceed with the UDP was undertaken on behalf of BTI by the Chief Executive Officer (CEO), who invented the bubble technology and formed the company when it was spun out from AECL.

1.3 Microgravity Expectations

BTI entered into contractual arrangements with the UDP with the expectation that the R and D required to meet the needs of the space program would lead to products and/or processes that would increase the market for its products in terrestrial applications. The UDP has supported BTI in the development of detectors aimed specifically at radiation encountered in the space environment, with the expectation that these detectors will be used by the international space community.

2.0 PROJECT DESCRIPTION

The first requirement was to prepare a comprehensive description of the radiations encountered in the space environment. This was followed by an experimental program to develop detectors that would respond selectively to these radiations. These must be calibrated using appropriate facilities, some of which are in foreign countries.

2.1 Objectives

The objectives of the project are to:

a) provide a detailed assessment of the radiations in space and their relative importance for space missions;

b) make bubble detectors that should be capable of responding differently to protons, neutrons and heavy ions, so that such radiations can be differentiated;

c) check the properties of these detectors by exposing them to high energy radiation such as that encountered in space; and,

d) assess various methods by which signals from the bubble detectors can be transmitted instantaneously to earth to allow live-time radiation monitoring (e.g. by use of emitted light from the detector which can be converted to a transmittable electronic signal).

2.2 Methodology

Information has been collected for some years on the spacial and energy distribution of radiation encountered in space. This information was collated to define the type and energy range of particles to be selectively detected. The BTI findings are summarized below. There is little if any knowledge in respect of the neutron spectrum in space.

Mission	Main Hazard	Energy	Main Source
LEO - Inner Van Allen belt	*protons electrons	100 MEV kev	solar, cosmic radiation
LEO - Outer Van Allen belt	protons *electrons	MEV MEV	solar, cosmic radiation
Outer Space	protons heavy ions	MEV	solar flare extra-galactic
Outer Space	protons	kev-MEV	solar wind,flare, EVA extra-galactic
	electrons	kev	solar wind

* - most hazardous for the mission.

As a result of the review, BTI decided to concentrate initially on the development of detectors that would differentiate between the presence of protons, neutrons and heavy ions.

The company designed a detector to respond to protons in the energy range 10 to 400 MEV, and to be insensitive to electrons. The energy range is appropriate to dosimetry in space.

The neutron detector was designed to record neutrons in the range from less than 100 kev to well over 20 MEV, and to be insensitive to protons.

The energy range of the heavy ions varies over orders of magnitude. The design of the detector was chosen to avoid interference from protons or neutrons.

BTI constructed a number of detectors using variations in the parameters. They exposed these to the appropriate conditions through the French space dosimetry group at the Synchro-cyclotron in the Institute of Nuclear Physics in Orsay, France.

2.3 Schedule and Budget

The project was initially funded over the period August 1988 to March 31, 1989, at $138,079. The project is receiving further support.

3.0 RESULTS

3.1 Degree of Success

BTI provided a neutron detector for the USSR Biocosmos 9 mission in September 1989. The detector appeared to record an accurate neutron dose. It also showed the unexpected presence of high energy neutrons. This finding has sparked interest throughout the USSR and European space community.

The USSR has proposed a program to continue the investigation. This will involve measurements at Dubna and space missions carrying bubble detectors. This interest by the USSR is now driving this aspect of the detector development program.

The results of the tests carried out at the Institute of Nuclear Physics showed that the detectors responded to radiations as expected. During the testing, it became apparent that the instrument being used for calibration was itself not capable of differentiating between types of radiations in all conditions. Nevertheless, the results obtained demonstrated the validity of the design principles of the bubble detectors. It now remains to construct prototype detectors and quantitatively assess their performance.

One objective was to investigate methods by which detector signals could be transmitted to earth in real-time. The company investigated the use of light emission and infrared emission. The results show that the problem is difficult to overcome, and that additional fundamental investigations are required.

3.2 Problems Encountered

Calibration of high energy particle detectors requires access to particle accelerators. These machines are heavily used and scheduling is carefully controlled. Access outside of the schedule is difficult. This has implications for projects such as the present one where there is a relatively short completion time.

Arrangements for use of the accelerator at CERN were made to test the detectors. During earlier work, BTI had made use of this facility to test a heavy ion detector. However, its behaviour in the presence of high energy protons was unknown. The start-up of the CERN proton accelerator fell behind schedule, and therefore could not be used in the present work. Testing was arranged at the Institute of Nuclear Physics in Orsay.

An acceptable method for transmitting detector signals awaits further basic investigation.

3.3 Expectations Met

The objectives as set out above were met within the time and budget allowed.

3.4 Benefits

Canadian technology for real-time dosimetry is in the forefront when applied to measurements in space. General international agreements are in place with France and the USSR under which BTI delivers dosimeters for use in their respective space programs. One benefit is the enhancement of Canada's image as a producer of high technology items, and the resulting international cooperation in space programs.

This project has advanced the bubble technology, by supporting the development of detectors capable of differentiating between different types of radiation.

3.5 Spin-offs

Terrestrial spin-offs are yet to be realized. The UDP support has opened markets in other space programs.

3.6 Client Interactions

These have been very good, particularly since the company relies on R and D funding for much of its revenue.

4.0 CONCLUSIONS

This project is an example of a technology that was already developed for terrestrial applications, and which is being adapted for space applications with the expectation that the knowledge gained will be reflected in improved and diversified terrestrial products.

It is unlikely there will be an extensive market in space programs for bubble detectors. However, they could become a standard for astronauts, and would be useful for measuring the radiations found inside unmanned satellites. Such knowledge is important for understanding the effects on delicate electronic components of particles ejected from the walls of space craft by the action of energetic radiation from space.

There is no production line for space dosimeters at present. BTI supplies each item on a custom basis.

The impact of the knowledge and experience gained through this project on new terrestrial products is uncertain, and will only be assessed in the future. Thus, while the company performed as required and the UDP is obtaining the detectors for which it contracted, product development by the company based on this work is questionable.

Demonstration of Canadian technology is resulting in more interest in joint space programs with the USSR and the French program.

4.1 Success Factors

- A scientific authority (SA) who knows what is wanted.
- Confidence of the SA in his own judgement of the importance of technological developments.
- Ability of the SA to assess the project scientifically.
- Establishment of trust between client and customer.

4.2 Strengths

- Good administration by NRC.
- Technical competence of performer.
- Project was need driven.

4.3 Weaknesses

- The Supply and Services Canada (SSC) process is too slow to accommodate requirements of international protocols.
- BTI is an R and D company; it is profitable but does not appear to have developed a sustainable market for its products.

4.4 Opportunities

BTI has potential for capturing a significant fraction of space dosimetry. Their technology may have more extensive market applications beyond the dosimetry field, but the company has difficulty taking the steps necessary to seize these opportunities.

4.5 Adminstration

Relations with UDP have gone well. Those with SSC rather less so, due apparently to delays.

BTI did eschew discussions with NASA as a result of experience with the administrative process in that organization.

5.0 OBSERVATIONS

Robert Apfel, Yale University, holds a patent on bubble technology issued in 1979, and formed Apfel Enterprises in 1987. He provided Harry Ing with copies of his articles and preprints, and stated that Harry Ing based his development on Robert Apfel's work. Both companies are developing and producing radiation detectors based on bubble technology.

BTI will have difficulty surviving without a sustained market. They have recently added an experienced manager, technology applications (market manager), and this may close a dangerous gap.

If they do develop a production line, there is an issue of where the company will locate. As long as BTI is R and D intensive, it can operate in Chalk River. If the company grows to require extensive production facilities, the lack of a local work force will cause it to move. If it requires very extensive production facilities, the work may well be done off-shore. In the event the latter occurs, the return on investment will be in royalties only.

BTI has achieved a high profile with both levels of government, and there may be unrealizable expectations in those quarters.

The board of directors are aware of the issues facing the company.

Individuals Contacted

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Appendix IV

Case History

Canadian Astronautics Limited

Development of a Floating Zone Semi-Conductor Manufacturing Facility in Microgravity.

Canadian Astronautics Limited
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Case Study

1.0 BACKGROUND

1.1 Company Profile

Canadian Astronautics Limited (CAL) entered the aerospace industry in 1974 and has specialized in

- space systems;
- radar and communications systems;
- advanced systems; and,
- defence electronics.

The company has more than 350 employees, about 70% of whom are professionals. Facilities include production facilities, laboratories and clean-rooms for aerospace hardware.

CAL, through the Space Systems group, is a major sub-contractor for the Mobile Servicing System, providing design and construction of the power and data handling subsystems. The company is also a major payload sub-contractor in the Radarsat program. The Space Systems group will provide the advanced reconfiguration C-Band antenna for this project. Contract R and D in the field of materials processing in microgravity falls within the responsibility of the Space Systems group. There are 76 people, of whom 50 are professionals, in this group.

The other groups provide a range of instruments, some of which they sell throughout the world. The Space Systems group does not have a production line. There is however, a move to develop a market for some of its products, anticipating the need to diversify beyond contract R and D and become more product oriented.

1.2 Microgravity Connection

The company based the decision to participate in the User Development Program (UDP) on the existing work on space hardware by the Space Systems group. This group had already developed capability in the design and construction of equipment for scientific studies in space. In 1991, NASA will fly the Wind Imaging Interferometer (WINDII), an instrument for upper atmosphere research.

CAL's experience was as a supplier of space hardware, and it therefore turned to the construction of a specialized furnace for growing crystals in space as its entry into the UDP. This required partners; the company took on one to provide and evaluate materials, and one to assess the value of the space-produced crystals for devices. Cominco Ltd.(now Johnson-Matthey Electronics Ltd.), Trail B.C., was the source of starting materials and did the evaluation; Aptec Engineering agreed to construct and test devices made from the processed materials. The three companies entered into the contract as partners.

CAL top management took the decision to proceed after extensive review within the Space Systems group.

1.3 Microgravity Expectations

CAL undertook the contract to develop a specialized furnace for processing materials, essentially semiconductors, in microgravity. Cominco Ltd. was seeking a profitable market for the by-product germanium. Aptec Engineering manufacture devices.

2.0 PROJECT DESCRIPTION

The microgravity project involved two components, the construction of a special-purpose furnace for use in the microgravity environment and the growth of large-diameter single crystals of high-purity germanium. CAL undertook to construct the furnace, Cominco provided the starting materials, and Aptec Engineering was to evaluate devices made from the processed ingots. The UDP conducted the project in phases to permit evaluations of progress at appropriate milestones.

2.1 Objective

The project objective was to

> Commercialize the manufacture of ultra high purity, large diameter germanium crystals in space.

In the context of this project, large diameter was taken to be in the order of 60mm. This is a significantly larger diameter crystal than is grown in a one-g environment by the float-zone method.

A subsidiary objective was to

> Develop the technology for float-zone processing of germanium in space which would establish an important base technology applicable to the space processing of other semiconductors.

2.2 Methodology

The company and its partners undertook a phase I study to review the current status of furnace technology and to develop a baseline design for an appropriate furnace.

CAL rejected crystal growth from a crucible, or otherwise confining the starting material, on the grounds that impurities from the container find their way into and contaminate the germanium. The company therefore selected the float-zone method. A key component was the heating furnace, selected to be a double ellipsoid halogen lamp.

The expected vehicle for the furnace was a Get-Away-Special (GAS) Can of fixed dimensions. The constraints on the design related to safety, power availability, thermal characteristics and heat generation.

The phased approach started with the construction of an engineering model to process a 10mm diameter ingot in one-g. The purpose was to test the design parameters. Fabrication of a flight model capable of processing 60mm diameter crystals would follow.

2.3 Schedule and Budget

The project encompassed the following phases.

Phase	Start	End	Cost
I	Pre UDP		
II	Nov. 1986	Mar. 1988	$977,568
III	Apr. 1988	Mar. 1989	$984,963
Final	June 1989	Mar. 1990	$359,277

3.0 RESULTS

3.1 Degree of Success

CAL constructed the furnace and used it in their laboratory to refine samples of high-purity germanium supplied by Cominco. Three or four samples were sent to Cominco for analysis and the results showed that there was a slight improvement in purity.

During the contract, terrestrial technology was developed to permit growing very large diameter germanium crystals - 8.5cm. These are substantially larger than the target diameter set for the project. Cominco Ltd. assigned two people for six months at company expense to produce pure germanium to use as starting ingots for furnace trials. They were unable to match the purity achieved by other suppliers. The combination of these two developments caused Cominco Ltd. to withdraw from the project. An incidental but not contributing factor was the sale of this part of the business by Cominco Ltd. to Johnson-Matthey Ltd.

The contract with CAL was amended to reduce the scope of work since the original user had withdrawn from the project. The revised contract called only for completion of the furnace.

With no materials from which to construct devices, the participation of Aptec Engineering was limited to assistance with a market study.

CAL expects to fly the furnace in the KC-135 in the Fall of 1990 with Dr. Floryan, University of Western Ontario as PI. He will have Prof. T. Carlberg, The Royal Institute of Technology, Stockholm, Sweden, as a co-investigator. The material will be germanium - from the stock supplied by Cominco.

The final design has some very attractive features. The heating element is toroidal in shape, with the element at one focus and the material to be melted at the other. A video camera has been mounted to give continuous monitoring of the shape of the float zone. Any deviations from the planned configuration of the float zone can thus be detected and corrective action taken.

The width, along with the speed of travel, of the float zone is monitored ultrasonically. Transducers are located at each end of the ingot to send and reflect the sound waves. The resulting pattern is analyzed and yields the depth of the float zone, the speed of travel of the zone, and some structural information on the zone. This technique can determine whether the whole zone is molten, or whether there is a connecting link between the two parts of the ingot.

Representatives from NASA, ESA and Japan have examined the furnace. Members of the Industrial Materials Research Institute (IMRI), National Research Council of Canada, have carried out tests with the furnace at CAL's facilities. IMRI and the University of Florida has asked for quotations on particular aspects of the furnace.

The NASA Center for the Commercial Development of Space specializing in crystal growth and located at Clarkson University and Case Western Reserve have shown interest. The former has asked for advice in respect of the video optics.

Teledyne, working with South West Research Institute, have a contract with NASA to produce a furnace for space processing. CAL is marketing their furnace to this consortium as a base technology.

The furnace appears to be a success, although there may not be many orders at $150K to $200K per copy.

There are additional Canadian users for the furnace. One PI from the Canadian Space Agency is planning an experiment using NaCl to be supplied by Dr. Reg Smith at Queen's University. The UDP is taking steps to have the furnace space qualified for use in the Shuttle, and perhaps later on Space Station.

3.2 Problems Encountered

The project has encountered a number of problems. A major one was the Challenger accident which has set back the availability of a GAS Can too far into the future to be useful for this project. CAL therefore redesigned the furnace to operate in the KC-135 aircraft. This problem was beyond the control of project management.

The unavailability of a GAS Can was compounded by the realization that the basis of the original design required re-evaluation. The original heating design called for the sample to be both rotated and move vertically past the double ellipsoid halogen lamp. This put too stringent requirements on the transport mechanisms. Furthermore, the energy profile in the ingot was not symmetric.

This finding led to a redesign of the heating mechanism to a ring or toroidal system, giving even heating and removing the requirement to rotate the ingot. CAL also decided to transport the heating system along the length of the ingot which would remain stationary, contrary to the original concept.

During the design phase it became apparent that the construction of a Demonstration Model was premature until the company understood more of the fundamental principles underlying the process of producing large single crystals.

The problems encountered led to a redefinition of the statement of work. An attempt to simulate the behaviour of the system was not successful and was dropped. The cost of experimentation in space led to a decision to focus on understanding the critical conditions within float zones produced on earth which result in crystals of the highest quality. These would then be used to determine the input parameters needed to produce crystals of this quality in microgravity.

The experience gained in the earlier phases suggested that the first furnace for use in space should focus on producing a 10mm diameter crystal.

The problems related to materials was noted above, and with regard to germanium remains unresolved.

There were problems from Cominco's perspective. Sporadic phasing of the overall project meant that employees would work for six months on a UDP contract and would then be idle or shift to another project while the next UDP phase was being negotiated (by CAL). The paper-work was also burdensome; 12-13 SOW's were produced for one contract - all at Cominco's cost.

3.3 Expectations Met

CAL has not been able to test the furnace in microgravity. The company has made a high quality furnace, but tests conducted in their laboratory gave inconclusive results with respect to improving on Cominco's high-purity germanium. There are some advanced features which may make it unique, and could lead to its use on space missions. Johnson-Matthey's (Cominco Ltd.) expectations were not met.

3.4 Benefits

CAL considers the furnace to be very good for space operations. The availability of continuous video monitoring is a major attraction. The design and engineering required demonstrate that Canada has the ability to produce hardware for space. This opens doors for international cooperation.

There may be some opportunities to provide users with a complete furnace or specific components.

3.5 Spin-offs

To date, the furnace development has created no spin-offs, but the new focus on product development could change that picture.

Johnson-Matthey did obtain spin-off benefits. The company built a plant at a cost of some $8M for producing germanium. The initial material produced did not meet quality standards, and could not be marketed. The company called in the team who worked on the CAL project and they solved the quality problem in two months. Their ability to do so is attributed to the experience gained in the UDP assignment on purification and characterization of germanium.

It should be noted however that this benefit has been short-lived. Johnson-Matthey has recently closed its Trail semiconductor facilities!

3.6 Client Interactions

CAL struggled during the early phases of the project. A formal review revealed the need to redefine deliverables and methodology. The company achieved the change in direction with some difficulty, and differences of opinion arose. These were overcome and a more fruitful relation emerged. During the later stages, client-contractor interactions are considered to be good.

4.0 CONCLUSIONS

The performance of the furnace in microgravity has yet to be determined. The flight in the KC-135 is expected to yield about 2 seconds of useful time to test the heating and control system and the ultrasonic measuring device. While the growth of high purity germanium did not proceed, the furnace can be used with other semiconductor materials. The furnace, or at least some of its components, will likely find its way into a crystal growing experiment in space.

4.1 Success Factors

- A good core technical team was established at CAL which stayed together throughout the project.
- Good customer relations (in the later phases of the work!).
- Client who knows what is wanted (critical review caused a re-evaluation of directions, resulting in a quality product).
- The UDP used outside experts as members of the project review team.

4.2 Strengths

- Phased approach.
- CSA listened to problems and assisted in finding solutions.

4.3 Weaknesses

- Poor customer relations during the early phases of the project.
- A poor presentation at the first review led to a CSA view that the work was poor.
- Trail turned out to be a poor location for production of high purity materials - there are too many pollutants in the atmosphere.

4.4 Opportunities

Apart from any further developments in Canada, the following are candidates for use of the furnace, or its components, in space programs.

NASA
ESA
Japan
University of Florida
Clarkson University
Teledyne/South West Research Institute

Specific technologies, such as the ultrasonic measuring system and the video monitoring may find application in terrestrial systems.

4.5 Administration

There do appear to have been problems with the administration of the contract - apart from the delays between phases as noted by Johnson-Matthey.

The process for soliciting quotes and informing bidders should be improved. As an example, Supply and Services Canada (SSC) recently sent an RFP to 160 potential bidders. SSC set a deadline for receipt of the bids and potential suppliers heard nothing for some months. CAL suggested that SSC send a letter to each bidder within a week acknowledging receipt of the bid. If screening is required, on completion of that phase, a SSC should send a letter to all who remain in the competition. This should also state when a decision will be taken.

The RFP itself should be accompanied by a letter to be returned to CSA informing the agency that a bid is or is not coming.

The UDP arranges for flight accommodation on the T-33, the KC-135, and the Shuttle. T-33 and KC-135 arrangements are relatively easy; the Shuttle is less so - unless a US PI is associated with the experiment. A determined and persistent Scientific Authority can create opportunities on the Shuttle. There are indications that the CAL furnace will fly on the Shuttle as a result of the actions of the Scientific Authority.

5.0 OBSERVATIONS

CAL believe that it was essential to have had Cominco Ltd. as part of the proposal in order to secure a contract. The Company takes this as a reflection of the desire of UDP to bring users into the program, not just hardware developers.

CAL may have sought advice from experts in the academic community, but there was no formal arrangement that would give a member of that community a specific item to deliver. If such an arrangement were in place, graduate students could be introduced to the space program.

CAL supports the annual users conference, and suggested there might be two, one for materials and one for life sciences. They were unaware of the annual UDP up-date publications. They would like to know more about budgets, who won contracts and the value of the contracts. (most found in the up-date)

CAL raised the issue of who will use space hardware and who will provide the funds. In the absence of some program to support experiments in space, the hardware will sit on the shelf and become obsolete.

Johnson-Matthey imply that they defined the furnace, and actually built the first model. CAL's first furnace did not work when tested at Trail!

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Appendix V

Case History

MPB Technologies Inc.

Development of Experiments on Crystal Growth of GaAs(In) by Liquid Phase Electro-Epitaxy (LPEE) in Microgravity

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Case Study

1.0 BACKGROUND

1.1 Company Profile

MPB Technologies Inc.(MPB), federally incorporated in 1976, specializes in technology systems and products and in contract research and development. The company has extensive facilities and concentrates on the design and fabrication of complex custom systems and high quality off-the-shelf products. Its areas of specialization are:

- communications;
- electromagnetics;
- electronic systems;
- fusion technology;
- lasers and electro-optics; and,
- space and photonics.

The company has about 180 employees, of whom about 34 hold Ph.D.'s and another 80 or so are graduates in engineering or science. Commercial work accounts for about 80-90% of company revenues, with the remainder coming from government. A large fraction of sales are off-shore.

1.2 Microgravity Connection

MPB was formed when RCA withdrew from R and D related to space communications. The founding members worked on space projects while with RCA, and the company worked on the Waves in Space Program (WISP). The link to R and D in the microgravity field was therefore a natural one.

1.3 Microgravity Expectations

The company entered the User Development Program (UDP) with the ultimate goal of preparing users for work on Space Station. The strong scientific base permits the company to select projects that will be attractive to scientists. They know what scientists need. This background led a decision to develop a space facility which would satisfy the needs of a number of investigators. The company expected that when the facility was constructed and proven in space these investigators would join with the company to carry out experiments. These experiments would take place initially in the Shuttle, and later on Space Station.

2.0 PROJECT DESCRIPTION

The project began in 1985 with a study to identify the type of facility that would be used for materials processing in microgravity by a variety of users. A review of

- user objectives;
- user facility requirements;
- limitations imposed by space vehicles; and,
- existing facilities.

revealed that space experimental equipment falls into one of two categories, common facilities or individual facilities. Common facilities tend to reduce delays in planning experiments, the cost, and project management. NASA, ESA and the USSR have each developed multi-purpose furnaces for crystal growth. Changing approaches, such as containerless processing have led to the construction of bulky and expensive hardware.

MPB concluded that one approach would be to construct a standard heating shell in which Principal Investigators (PI) could insert their own custom furnace. This shell would comprise

- a Power Supply Unit (PSU);
- a Control and Data Acquisition Unit (CADAU);
- a quenching facility, and,
- a furnace housing (Thermal Environment Unit, TEU) with a heat shield for thermal insulation.

With such a facility, the PI could satisfy his requirements by adding heating elements, heat profilers, and heat distributers.

This would reduce time delays and costs. Canadian companies could use the facility as an inexpensive tool to start their own development program.

MPB offered to design and construct a facility to meet the perceived requirement. They named the facility the Canadian Heating Apparatus for Material Processing in Space (CHAMPS)

The PI will specify the custom design furnace called the Adaptable Heating Unit. This unit will vary from one user to the next. The operational requirements will govern way in which CHAMPS interfaces with the experiment.

At the start, MPB expected CHAMPS to fly in a Get-Away-Special container. Ag-Zn batteries were to provide the power. The Control and Data Acquisition Unit comprised a set of digital electronics, based on a microprocessor, to control CHAMPS. The Thermal Environment Unit provided the environment within which the Adaptable Heating Unit would be installed.

Following the initial review of requirements and subsequent design of a furnace, MPB continued with the construction of a prototype CHAMPS - now renamed as Configurable HArdware for Multi-disciplinary Projects in Space. McGill University became a sub-contractor to provide a defined user with an experiment on Liquid Phase Electro-Epitaxy. The university was scheduled to provide the LPEE payload.

MPB has almost completed the prototype flight model. They have not carried out full tests.

McGill has had limited success in growing good quality in the laboratory using a closed cell technique. The performance must be improved before any flight experiments can be considered. The PI has left the university, and is not available to continue the investigations.

OMVPE Technologies Inc. acted as sub-contractors to evaluate the quality of the material produced by McGill. They conducted a number of experiments to satisfy themselves that they had the best procedure for etching GaAs. This was done using samples from manufacturers with known characteristics. They applied the technique to samples grown in the McGill laboratory, and concluded that they had the capability to evaluate materials grown in microgravity when such materials became available.

Opto-Electronics Inc. were also sub-contractors charged with developing methods for characterizing LPEE materials grown in microgravity used for optical detectors.

2.1 Objective

The original objective of the project aimed at construction of a multi-purpose facility to serve a variety of users. This was modified during the early phases of the work to include a specific investigation on the growth of GaAs(In) by LPEE.

2.2 Methodology

The project began with a thorough review of the current state of the art in respect of space processing furnaces, and an analysis of the expected requirements of users. This activity led to the concept of CHAMPS.

During the first phase MPB carried out its assessments. A design phase followed in which the company identified the individual components of CHAMPS and developed the specifications for each one. At this point, McGill joined the project to develop the LPEE payload.

In the latter phases, the company constructed a flight prototype CHAMPS. McGill worked on the payload. OMVPE Technologies became a further sub-contractor to characterize the McGill samples.

2.3 Schedule and Budget

The phasing and funding have been as follows:

Phase	Start	End	Cost
I	1985	Feb. 1986	$ Pre UDP
II	Nov. 1986	Apr. 1988	$ 956,005
III	Apr. 1988	Oct. 1989	$ 816,000
IV	Jul. 1989	Mar. 1990	$ 277,451
IVb	Jun. 1990	Mar. 1991	$ 196,396

3.0 RESULTS

The company is proceeding with the construction of a flight model of CHAMPS. The project team hope to be able to perform an experiment (LPEE) in the Shuttle some time in the next year. There are not many customers for CHAMPS at present, and that situation will continue until a successful demonstration takes place. MPB expects to propose experiments of its own for CHAMPS in the future.

3.1 Degree of Success

The Challenger accident set back the project. CHAMPS was designed to operate in the Shuttle or on Space Station. The time required to carry out an experiment precluded the use of the KC-135. An initial test must await accommodation on the Shuttle, or CHAMPS could be redesigned to operate in the KC-135 or other available vehicle, and acceptance by the scientific community depends upon the results of that initial test. The project manager expects to have the flight model and the LPEE experiment ready by the end of the current phase of the contract (March 1991). The facility will be constructed, but it may not fly until 1992-93.

3.2 Problems Encountered

A problem arose when the Principal Investigator (PI) for the LPEE left the university. MPB has now hired a materials specialist and is carrying on with that aspect of the project in-house.

3.3 Expectations Met

Achievement of the ultimate goal - preparing users for space - lies in the future. However, a flight model of CHAMPS is scheduled to be ready in March 1991. The shorter term goal of developing the facility will be met.

The company expected more rapid growth of materials processing in space using the Shuttle.

MPB is cautious about involving other investigators in CHAMPS until the facility has been tested by an actual experiment.

3.4 Benefits

The project has generated no revenue for the company apart from the contract itself.

The project has provided the company with the opportunity to develop competence in materials processing, and to become familiar with hardware, software and control systems for space applications.

3.5 Spin-offs

The company believes it can fabricate high-quality custom substrates for growing ternary compounds and there is a significant market for materials of this type. Ternaries cannot be fabricated using existing technology. Company capability will be a direct result of involvement with the LPEE process being investigated as part of the CHAMPS project.

3.6 Client Interactions

MPB were directed to move from the prototype directly to a flight model of CHAMPS. The step was too great, and the resulting design changes as the project progressed offset any expected savings in time and cost.

Project reviews took place as planned. However, in the earlier stages of the project there was little additional interaction between CSA and MPB. The project could have benefited from discussions outside the formal reviews. This situation has changed, and the project has benefited from technical discussions with the Scientific Authority.

4.0 CONCLUSIONS

4.1 Success Factors

- Involving a user with the facility.

4.2 Strengths

- The company has sufficient depth so that the project could be continued after the original proponent and project manager accepted a position with another organization.
- The company can move people between divisions as necessary to support projects.

4.3 Weaknesses

- Project relies on Shuttle or Space Station, neither of which are readily available.
- A corollary is there are few outside users for the facility.

4.4 Opportunities

There are opportunities for using CHAMPS:

- a small redesign would permit CHAMPS to be used on the KC-135, T-33 and Falcon-20; and,
- CHAMPS could be re-designed to fit a sounding rocket.

4.5 Administration

The administration of the project has gone smoothly, apart from perceived insufficient client interaction in the early phases as noted above.

One outside scientist was involved in the project review process.

The Scientific Authority is attempting to obtain space on the Shuttle for a CHAMPS experiment. As noted in other case studies, access is uncertain, but can be improved if a US PI is involved.

The UDP is also working on an agreement with the USSR. When this is completed, CHAMPS will be a candidate for a flight with the USSR.

5.0 OBSERVATIONS

In the short run the project will not achieve its goal. This is not a fault of the company, but rather a reflection of the lack of accommodation on the Shuttle. CHAMPS can be compared with LAMPS, the other major facility being constructed by MPB. In the case of LAMPS, the project started with a joint proposal from York University and MPB. The user was in at the beginning. As the project developed and was described at various meetings, additional participants joined. The process was therefore synergistic.

LAMPS has a second advantage in that it can be used in the KC-135. This means short turn-around time for experiments which draws PI's to the project.

MPB made an effort to involve users in the project. McGill was retained to grow GaAs(In) by LPEE. OMVPE Technologies Inc. were retained to evaluate the material produced. And Opto-Electronics Inc. were brought in as potential users of the final materials.

The President of OMVPE Technologies Inc. was a former graduate student of the PI at McGill. OMVPE appears to have gone out of business.

The Office of Research Contracts at McGill were unaware at the outset of their involvement that the contracting authority was SSC. For industrial contracts, McGill's policy is to add 100% of the salary component to cover the overheads. The University also requires up-front funding to avoid carrying costs. SSC will only pay 65% overhead, and their contracts are cost-reimbursable.

There was some negotiating with SSC in the early stages in relation to overheads that caused the University some trouble, but they do not want to make it a big issue. Apart form that, there have been no administrative problems with the MPB contract.

In total, the entire project was ambitious. CHAMPS has been successful as a hardware development. The user aspects have been less so. Part of the problem lay with the difficulty of producing materials - even in the terrestrial environment. Difficulty in accessing microgravity may have played a part also, although putting the hardware into microgravity without the companion materials processing experiment would serve no purpose.

MPB has developed considerable capability to undertake space projects, and is committed to this aspect of its business. There are plans for long-term - 10 year - experimental projects, probably in partnership with a university.

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Appendix VI

Case History

Prof. Don Brooks

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Structure of Flocculated Polystyrene Latex Under Constant Shear

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Case Study

1.0 BACKGROUND

Dr. Brooks has engaged in projects making use of microgravity conditions for many years. He began with a collaborative experiment with members of the staff of the University of Washington in Seattle. This group had arranged access to the Space Shuttle in its early days.

That experiment involved separation of two different biological cell types added to a mixture of immiscible liquids. Shaking the mixture in near-zero gravity caused the two cell types to attach themselves to one or other of the liquids. This project continued with an experiment on the KC 135 in October 1987. Another experiment is ready and waiting for the appropriate shuttle launch.

1.2 Microgravity Expectations

Dr. Brooks' current project deals with the flow properties of dispersions of latex spheres in aqueous media. It arose from the observation that when latex spheres are coated with a film of the appropriate material, blood cells with specific antigens form bonds to the spheres. The method is standard for determinations of specific antigens in blood. The process results in the formation of chains of cells and spheres. These chains become dispersions. The study of these dispersions led to the present project, which investigates the principles involved in dispersion formation and behaviour of latex spheres.

When the dispersion is subjected to simple shear, under certain conditions, long range ordering of the spheres takes place. Dr. Brooks is investigating this phenomenon, and will perform experiments in microgravity if results of terrestrial experiments suggest that this would be useful.

2.0 PROJECT DESCRIPTION

Knowledge of the flow properties of dispersions of particles in aqueous media is necessary to understand the behaviour of these media in a variety of natural and industrial settings. Paints, inks, cellulose slurries, coal suspensions, slurries in ceramic slip-casting and blood cells in circulation are examples where particle dispersion plays an important role in determining the behaviour of the medium.

The characteristics of the medium, the concentration of particles, and the interaction among the particles together determine the flow properties of suspensions. Shear flow strongly affects particle-particle interactions, since the local flow direction and shear stress produce both collisions and separation.

The characteristics of suspensions of aggregating particles are difficult to study since the aggregates form a sediment and produce non-uniformities in the suspensions as their size increases. A low-gravity environment therefore provides an advantage for the study of such systems, since the effect of sedimentation is greatly reduced.

The present investigation deals with a dispersion of latex spheres in an aqueous medium. When such a system is subjected to simple shear, visible aggregates form and arrange themselves in a regular two-dimensional, roughly rectangular lattice. This lattice gradually degrades as the aggregates form a sediment.

2.1 Objective

This project is scheduled to be completed over a four year period, commencing in October 1988. The objectives are to

1. Design and construct a versatile cylindrical shearing device which will allow independently controlled counter rotation of the central bob while the outer cylinder rotates;

2. Develop approaches to analysis of images of the long range structures and geometry of the growing aggregates;

3. Fully delineate the envelope of conditions which produce dispersion structuring under shear in the sulphated polystyrene system and the conditions beyond which sedimentation affects the phenomenon;

4. Investigate the kinetics of the structuring and attempt to interpret them in light of current theories;

5. Investigate shear-induced structuring in other systems to model dispersions of industrial interest;

6. Survey the potential industrial interest and academic user community in Canada to determine the level of interest in developing a Canadian rheological facility for the Space Station environment; and,

7. If appropriate, design a space experiment aimed at studying the dispersion structuring phenomenon in the absence of sedimentation interference.

2.2 Methodology

The project is moving forward in a phased approach that allows the results of the previous phase to determine the content of the next. Under an initial six month contract, an investigation was undertaken to be sure that the observed phenomenon was real and not due to effects of the apparatus.

Once the existence of the phenomenon was confirmed, a prototype shearing apparatus, along with recording devices, was constructed.

The apparatus consists of the shearing machine, a controller, a frame grabber, and the associated software to control the operation and simultaneously perform the analysis. Development of the operating aspects of the apparatus has been sub-contracted to Quantum Vision Corporation. This company is owned and operated by an individual, Andrew Brown, who is associated with (but not a member of) the Applied Physics Department of the University. The technology is based on an apple sorter developed by the company.

This is to be followed by a second generation shearing apparatus with automated control and data recording/analysis. Flight apparatus will be built if it is considered appropriate to study the phenomenon in microgravity.

2.3 Schedule and Budget

The schedule and phases of the project are as follows:

Phase	Start	End	Cost
I	Oct. 1988	Mar. 1989	$ 31,747
II	Jul. 1989	Apr. 1990	$ 118,426
III	Oct. 1990	Oct. 1991	$ 144,770

3.0 RESULTS

During phases I and II of this project, Dr.Brooks constructed a simple shearing device capable of demonstrating that the observed ordering was not due to wall roughness. He included a system for direct video imaging and analysis, introducing the possibility of developing a fully-automated apparatus.

The development of software to control the analysis has been key. For fully automatic operation, the video image must be continually captured and analyzed for size and position of the components of the dispersion.

The initial qualitative assessment of conditions which lead to shear-induced structuring in polystyrene latex suspensions has begun.

3.1 Degree of Success

The feasibility study conducted in Phase I led to the conclusion that the phenomenon was worthy of investigation and that experiments in the absence of sedimentation would provide information to explain the observations. The work in Phase II has dealt with the construction of the shearing device and the image analysis system.

3.2 Problems Encountered

One problem encountered relates to the ability to define the actual software required. This results from a combination of design changes as the apparatus develops and from the approach taken by the writer. There has not been sufficient money available to cover the costs of programming, with the result that the software writer has been able to recover the full costs of his efforts. This may be due in part to the rigorous approach taken.

3.3 Expectations Met

Dr. Brooks has laid out a structured approach to the investigation of the two-dimensional lattices formed when latex spheres in an aqueous medium are subjected to simple shear. The phased approach identifies milestones when progress can be assessed and a decision to proceed or terminate can be taken. Phase I demonstrated feasibility. Phase II has deal with construction of apparatus to observe the phenomenon in the laboratory. Phase III is about to begin during which the conditions leading to the structured dispersion will be investigated.

3.4 Benefits

The major benefit to the UDP lies in retaining the participation of a competent and energetic research worker. Dr. Brooks has assumed the chairmanship of the Canadian

Users Committee for Space Station. In that capacity, he has encouraged the appropriate communities to seek opportunities for investigations in microgravity, and in particular, to give thought to the best way for Canada to take advantage of its allocated use of Space Station. The program needs this type of support from the community if Canada is to achieve any user benefits from its contribution to Space Station. And it helps to have advocates from the university community who can be considered the main users for the foreseeable future.

3.5 Spin-offs

Although problems have arisen in respect of software, nevertheless one package developed for this project has been sold to another group in UBC.

Although no new product has resulted from the project, the experience gained has been factor in allowing Quantum Vision Corporation to acquire a contract to develop similar motor controls for another client.

3.6 Client Interactions

These have been good, although there is not perceived to be specific knowledge in the subject area of this project. UDP helped to put Dr. Brooks in contact with other investigators interested in work in microgravity.

It was suggested that

- UDP could increase its efforts to bring people together who have common interests;
- everyone receiving support should be required to report on their work in a forum where others can be present; and,
- UDP could monitor projects more closely.

4.0 CONCLUSIONS

4.1 Success Factors

- A well-defined problem; the presence of the effect was known before support was solicited.
- There is an exceptionally good shop group available to support the project.

- Space qualification is undertaken by industry; the research work is done at the university.

4.2 Strengths

- UDP is perceived to obtain a lot of activity for the funds expended; this is true at least for the university participants.

4.3 Weaknesses

- People issuing contracts could have more detailed knowledge in the subject area.

- There should be more university/industry interaction.

- There should be a strategic plan; the US OSSA has a strategic plan that is perceived to be very good, and is justified to Congress annually.

4.4 Opportunities

Dr. Brooks' apparatus may be a candidate for installation on Space Station.

4.5 Administration

- The UDP office should be set up to assist with paper work; one Ph.D. spends full time on paper work for participation in IML-1; the example to emulate is the Canadian Astronaut Program office which is considered to take on much of the paper burden.

- There is excellent support for the KC-135 program.

- UDP should examine the paper requirements - these may discourage some potential participants.

- UDP might be able to provide assistance on where to make purchases.

5.0 OBSERVATIONS

Dr. Brooks proposes that his apparatus for investigating dispersions be a candidate for the Canadian use of our 3% of the facilities on Space Station. He believes there is, or could be, sufficient interest in the academic community to make effective use of such equipment. A favourable decision in this respect would have to await results from his own experiments to be sure that such an investment warrants consideration.

He does not believe that the life science community will be the major user of the 3%. This is based on the notion that astronauts, all with many duties to perform, will be used a subjects. They will have no time for body experiments. Dr. Watt from McGill will present a paper in Rome at the International Forum for Scientific Uses of Space Station in which will make this point.

This question of who will use Space Station for what purposes is one that should be addressed now. If we leave it for the next generation, the necessary ground and KC 135 work will not have been done. If we are not going to use our 3%, we better find a buyer or have some explanation ready when our leaders ask why we persuaded them to make the 1B dollar plus investment. Maybe we leave that to the next generation too!

Andrew Brown of Quantum Vision Corporation had no opinion on the management of the project, other than to express satisfaction. He was only a minor player (in the administration) - did his work and submitted his bill. He is part of the new proposal, so the team works well together. Quantum Vision Corporation is small, probably one-man, operated out of Andrew Brown's house.

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Appendix VII

Case History

ThermaZone Engineering Inc.

A Study for the Development of a Compact Gradient Freeze Furnace for Controlled Growth of High Quality Crystals.

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Case Study

1.0 BACKGROUND

ThermaZone Engineering Inc. was formed in 1986 following the demise of a company established by the same principals ten years earlier to develop solar heating systems. The previous company was R and D intensive, and survived on contracts which dried up when oil prices did not advance as predicted. There was core capability in software development for PC-based control systems.

1.1 Company Profile

ThermaZone has 15 employees of whom 8 are professionals. It has developed a software program to read graphic and text files created with CAD and Desktop Publishing software packages. The program converts each file into a format to drive vinyl cutters in a way suitable for use in producing signs. It is aimed at the signmaking/silkscreening industry.

The advantages of this program are that it combines with off-the-shelf products such as PC's and commercial software and therefore avoids the need to purchase specialized systems. A user can create new art quickly and can recall repeat orders immediately from computer memory.

In addition to the control software, ThermaZone has developed a hardware interface between the computer system and a Gerber vinyl cutter.

The company estimates the world market for cutters to be about 100,000, with Gerber holding about 30%. Annual sales are about 15-20,000 units.

ThermaZone intends to remain an engineering design company and is not contemplating establishing production facilities.

1.2 Microgravity Connection

Queen's University runs a four day symposium each spring to bring together the graduating students and the "real world". Mr. Ramsden, a graduate of Queen's, was a speaker at one symposium. He met Dr. Reg Smith there, and from that meeting the concept of a project to enlarge the capability of the Queen's furnace QUEST developed.

The User Development Program (UDP) provided ThermaZone with its start-up contract. The modelling and software control capability developed in the solar program provided the necessary background to develop a specialized furnace for growing crystals in microgravity. Reg Smith acted as an advisor, and Queen's did testing and some of the construction.

1.3 Microgravity Expectations

ThermaZone expects to use the experience gained in the microgravity project as start toward building a commercial furnace for crystal growing. They do not expect to provide many microgravity furnaces, counting rather on the terrestrial market. In this market, the first users will be university researchers and R and D laboratories. At present there are no low cost furnaces of the type being developed by ThermaZone. The company expects its model to sell for about $20,000, compared to $150,000 for competing models. ThermaZone estimates the worldwide market to be about 2500, leading to expected sales of about 50 units per year.

If the present R and D furnace is successful, ThermaZone may go on to develop a production model for use by companies such as Alcan and Noranda in their casting processes.

2.0 PROJECT DESCRIPTION

In Phase I, the contractor reviewed the literature to determine what information exists on theoretical models of multizone furnaces, general thermal models, and equipment suppliers. ThermaZone examined the characteristics of the Queen's furnace in particular. They used this information as a basis for development of a thermal model for the design of a 25mm diameter directional freezing furnace. The company constructed a prototype model describing the behaviour of the sample and compared its performance with experimental measurements.

In a follow-on Phase II, ThermaZone extended the model to include the behaviour of the furnace as well as the sample. They introduced a number of other improvements in design with the intention of moving toward a space-ready facility. Verification of the model for several materials was also undertaken. The company undertook a market study for a commercial furnace as part of this phase.

Queen's university is a sub-contractor on this project. Dr. R Smith acts in an advisory role, providing and evaluating samples and commenting on the furnace design.

A furnace is being constructed for test in a KC-135 flight. Dr. Smith is the Principal

Investigator.

2.1 Objective

The objective of the project was to develop and test a prototype 25mm diameter multizone furnace and study containment techniques for processing in microgravity.

The expectation was there would be a small market for space applications, and an additional market for a sophisticated furnace of modest cost in terrestrial applications. ThermaZone recognized however that most of the users would be working in R and D.

2.2 Methodology

The first step involved the development of a thermal model to aid in the design of the furnace. ThermaZone has developed a number of computer-based models and they examine these to assess their applicability to the present requirement. Based on one of these, a finite element model was constructed for a PC to determine the energy flows in a sample.

The results of the modelling were used to decide on

- the size of the power supply;
- the number of heating zones; and,
- the conditions to be imposed on heat input or extraction.

ThermaZone selected an eight zone furnace, with the temperature of each zone controlled so that a molten ingot in an ampoule within the furnace could be cooled from the bottom upwards at a given rate.

Six inlet cooling jets were incorporated into the design.

ThermaZone set the resulting design requirements as follows.

Physical dimensions

length	250mm
diameter	25mm

Operating Requirements

materials	low temperature, semiconductors
growth rate	1 to 100 microns/second
temperature gradient	10 to 100 degree C/cm
maximum temperature	1250 degrees C

Environmental Requirements for Space

maximum current per element	10 amps
voltage available	28 volts

The company constructed a furnace over a three month period and ran test using tin, a steel bar, and an aluminum-copper eutectic.

They undertook further development of the furnace and refinement of the model in Phase II.

2.3 Schedule and Budget

The project has been broken into phases as follows.

Phase	Start	End	Cost
I	1986	1987	$ 94,625
II	Mar. 1988	Mar. 1990	$411,182

The value of the contract was reduced to $ 257,679 in 1990.

3.0 RESULTS

3.1 Degree of Success

The thermal modelling was able to predict the general operating characteristics of the furnace, and was successful in determining the size of the power supply and the form of the cooling system.

The furnace control operated quite well, and temperature gradients of 10 to 100 degree C/cm were maintained.

The company will make a final assessment when they complete the KC-135 flight experiments.

ThermaZone aims to develop a commercial market for its furnace. While the market survey produced estimates for terrestrial sales, the same was not true for microgravity applications. The company found that investigators working in microgravity were reluctant to discuss their plans or their needs. That market therefore remains uncertain.

The information gained in the market survey has led to some design changes. Terrestrial users made useful suggestions. For the reasons mentioned above, potential microgravity users did not make similar contributions.

3.2 Problems Encountered

Lack of available space on the Shuttle caused a deletion of the development of a space qualified furnace from the contract.

3.3 Expectations Met

Expectations fall into three categories:

- providing initial support for the company;
- developing a furnace for use in microgravity; and,
- developing a commercial product.

The first of these expectations has been met. KC-135 trials will determine the success of the microgravity furnace. And commercialization is in the future.

3.4 Benefits

1. The UDP contract was responsible for the successful formation of what is now a viable company.
2. The sub-contract with Queen's University has brought a faculty member and graduate students into the project, and therefore enlarged the microgravity user community.

3.5 Spin-offs

While it may be difficult to directly link the UDP contract with the current business of the company, the knowledge and capability in software development and control systems that led to the award of the contract are the same skills that are the basis of its main product. Thirteen of the fifteen employees are working on developing products. Two are working with the furnace.

The market study suggested there are terrestrial applications for the type of furnace ThermaZone has designed. If they can sell 50 units per year, the product will be a commercial success. The company expects to distribute the furnace through the companies that are now servicing the research community.

3.6 Client Interactions

The client interactions have been good.

4.0 CONCLUSIONS

4.1 Success Factors

- The company had technical expertise, and had part of the technology required.
- An end user (Queen's) was part of the project thus ensuring relevance.
- The end user was well-informed, resulting in the development of a near-leading edge furnace.
- Arrangement with the client were generous, permitting ThermaZone to develop the furnace the way the company wanted.
- The scientific authority was familiar with the technology.

4.2 Strengths

- Lack of rigidity on the part of CSA.
- The Scientific Authority understood what was being done and knew what other developments were taking place in the subject area.

4.3 Weaknesses

- The time taken to introduce new phases to a project places a strain on companies that must find work for employees.
- There is a concern that UDP funding may not be adequate to complete the process that has been started.
- The program lacks a directed mechanism for ensuring a link between the developers and the end users.

4.4 Opportunities

ThermaZone does not see itself as a major supplier of space hardware. However, provided the furnace under development behaves as expected, there may be a terrestrial market. Future applications in space are uncertain.

The UDP considers this project to have a high potential for spin-offs. In addition to a market for the furnace itself, the modelling capability developed within the company should be used in many other applications.

4.5 Administration

The project was well administered from the company's point of view.

Project reviewers included experts from government laboratories.

5.0 OBSERVATIONS

This case is a good example of how a government contract can provide the funding to allow a start-up company to develop a market niche. Before winning the furnace contract, ThermaZone had no involvement with the space program. It appears that its entry into the field arose through contact with Reg Smith. The principals had been referred to him while looking for opportunities in the solar heating field. Queen's were developing a furnace for processing in microgravity, and ThermaZone's capabilities in computer control could be matched with the control facilities needed for the Queen's furnace.

The original objective was to develop a furnace for use in the Shuttle or on Space Station. The UDP reduced the scope of the project when it became apparent that adequate access to either of these platforms would lie well in the future. The revised objective called for the production of a terrestrial furnace that would be attractive to PI's in the materials field. Their use of the furnace for terrestrial experiments would lead to an easy transition to the space environment since the equipment would not change. Thus, the furnace would be used to promote the use of microgravity.

The point was made that development projects should be "need driven." It was suggested that some forum should be established, a "round table", to bring Principal Investigators (PI) and manufacturers together so they could pair into teams. The idea of building pairing into contractual requirements was rejected on the grounds that a manufacturer would engage the services of any available PI rather than the most appropriate. Similarly, the annual users symposium was unsuitable since it involves primarily organizations that are already working in the program.

Thermazone conducted a "market survey" for its furnace. The conclusions suggested that there would be a market for about 50 furnaces per year - enough to pursue. The August 1990 edition of Physics Today, Part 2, lists 49 different companies offering furnaces for annealing, diffusion and laboratory. Dr. Smith pointed out that the ability to sell the furnace will depend upon price. He believes that at $20,000 a unit, there would be a market. Comparable furnaces sell for $60-100,000.

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Appendix VIII

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