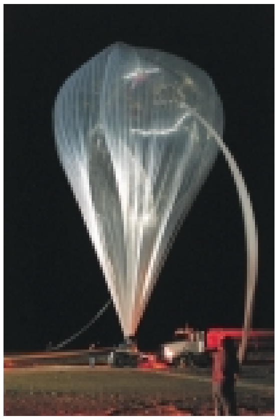
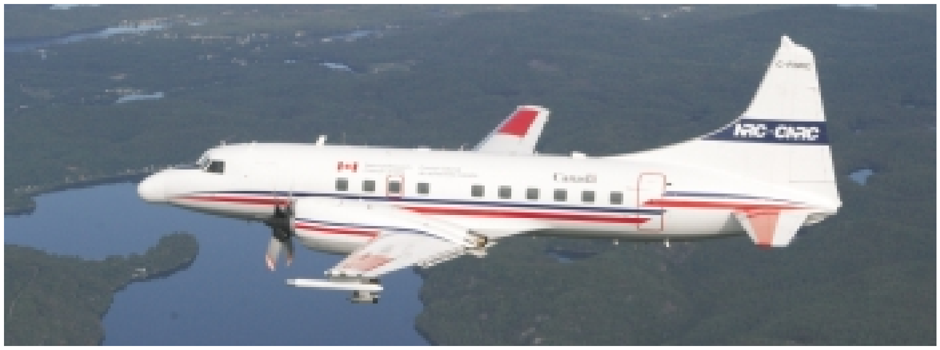




Photos courtesy of Environment Canada, National Research Council Canada, and Paul Nicklen

Community Workshop on Science from Suborbital Vehicles (Balloons, Aircraft, Sounding Rockets)

Toronto, Ontario, Canada

McTaggart-Cowan Auditorium at Environment Canada
4905 Dufferin Street, Downsview, Ontario

February 1 and 2, 2007

Final Report

This Workshop was supported by the Canadian Space Agency and hosted by Environment Canada.

Environment Canada Environnement Canada

Final Report

For the

Community Workshop on Science from Suborbital Vehicles
(Small Payloads Program Workshop)

Submitted to

Canadian Space Agency
Space Science Program

Submitted by

Kimberly Strong, University of Toronto (Committee Chair)

On behalf of the Workshop Organizing Committee

Doug Degenstein, University of Saskatchewan
Michaela Hegglin, University of Toronto
Dave Knudsen, University of Calgary
Tom McElroy, Environment Canada
Barth Netterfield, University of Toronto
Ben Quine, York University
Walter Strapp, Environment Canada
David Tarasick, Environment Canada
Kaley Walker, University of Toronto
Jim Whiteway, York University

March 31, 2007

Table of Contents

1. Executive Summary

The Community Workshop on Science from Suborbital Vehicles was held in the McTaggart-Cowan Auditorium at Environment Canada, Downsview, Ontario, on February 1 and 2, 2007. This Final Report provides an overview of the Workshop, a summary of the discussions and break-out sessions, and a set of recommendations. This Report will be released to the community after review by the Canadian Space Agency.

The aim of this Workshop was to bring together those in the Canadian science community who have an interest in using balloons, aircraft, and sounding rockets as platforms for scientific exploration, and to get them dreaming about new ideas. The concept emerged from discussions about the future of scientific ballooning in Canada, and a two-day workshop was proposed to the Canadian Space Agency in July 2006. CSA welcomed this idea and agreed to provide some funding in support of the Workshop.

The Workshop was intended to be relevant to all communities included within the scope of the upcoming Announcement of Opportunity (AO) for Small Payloads, and was widely advertised to those communities. It encompassed science from suborbital vehicles, including balloons, aircraft, and rockets. Such platforms offer a number of advantages that are closely allied to the mission of the Canadian Space Agency. These include:

- Scientific exploration, including atmospheric science, space science, astronomy, and astrophysics
- Technology development, including testing prototypes of satellite instruments
- Validation of satellite missions, such as those making height-resolved atmospheric measurements
- Training of scientific and technical personnel, who will become the next generation of scientists, including our next generation of Principal Investigators

The goals of the Workshop were:

- To raise the profile of balloons, aircraft, and rockets as platforms for scientific investigations
- To stimulate discussion of new approaches and new science questions that can be addressed with such platforms
- To determine the level of interest in these flight opportunities in Canada
- To identify the infrastructure needed to enable new missions
- To provide a vision for a "program" with regular flight opportunities
- To enhance and create new collaborations between Canadian universities, government agencies, and industry

The expected outcomes of the Workshop were:

- A ten-year vision
- A game plan for the next year
- A list of potential new missions
- A description of the infrastructure that will be needed for each platform, to allow such missions to be accomplished
- Recommendations for what is needed to maintain continuity

Ideally, we would like to see the outcomes and recommendation emerging from the Workshop providing input to the anticipated Announcement of Opportunity (AO) for the new Small Payloads Program. If the timing of that AO makes this impossible, then we hope that these would provide input to the subsequent Small Payloads AO.

Our overall ten-year vision for suborbital missions is to establish an active and viable small payloads program whose importance in contributing to scientific exploration, instrument development, and training is recognized at CSA and in the wider community. This program would engage Canadian universities, government agencies, and industry, and would consist of regular flight opportunities for all three platforms. It would have the flexibility to support flights of both new and proven instruments, to enable the development and implementation of new technologies and capabilities, thereby leading to greater opportunities for new and exciting scientific missions.

To enable this ten-year vision to become a reality, the Workshop recommended that the CSA:

<u>Aircraft</u>

(1) Include aircraft as platforms within the scope of the Small Payloads Program.

(2) Provide funding for the use of aircraft for instrument testing, characterization, and validation. This would include the costs of installation as well as the aircraft operations.

(3) Provide 20% matching funds for applications to the Canadian Foundation for Innovation (CFI) for aircraft infrastructure. This would include testing and characterization of instruments being developed for CSA missions.

<u>Ballooons</u>

(1) Establish and maintain a Canadian-led stably-funded, long-term (10-year) balloon program, with regular flight opportunities, enabling a minimum of two flights per year. An active, ongoing program supporting several overlapping balloon projects at different stages would require a budget of at least $1M per year.

(2) Provide a mechanism for funding international opportunities as they arise, facilitating this in a timely manner. For example, flights of opportunity may well have timelines on the order of 3 to 6 months. If we are to take advantage of such opportunities, then CSA must be able to review and fund them in a time frame that may be on the order of a few weeks to a few months in advance.

(3) Fund the development of new instrumentation.

(4) Ensure that there is support for balloon flights of both new higher-risk instruments as well as well-proven ones.

(5) Provide strong support for test flights of future satellite instruments on balloon platforms, prior to their deployment in space.

(6) Actively support the involvement of students, postdocs, and younger scientists in ballooning.

(7) Have realistic expectations for the management of large and small projects by university-based investigators.

(8) Undertake multi-agency co-ordination of support for missions, insofar as possible.

(9) Give consideration to leveraging of CFI or other funding in the upcoming Small Payloads Program Announcement of Opportunity.

(10) Support the community's efforts to achieve new Canadian capabilities, such as a long-duration balloon flight capability, an Arctic launch capability, and/or a deployable launch capability.

(11) Arrive at an agreement leading to the upgrade or replacement of the launch support infrastructure at Vanscoy, in partnership with Environment Canada.

(12) The Canadian ballooning community reconvene to make a coherent plan with firm recommendations regarding the future of Canadian launch capabilities.

Sounding Rockets

(1) Maintain and enhance Canada's ability to participate in international collaborations by i) ensuring sufficiently frequent and regular AO's, ii) forming or supporting working groups with both agency-level and scientist-level participation to develop bilateral collaborations in specific disciplines, and iii) weighing carefully the decision no longer to accept unsolicited proposals, which have been the mainstay of Canadian participation in international space science missions and scientific instrumentation programs for decades,

(2) Fund a Canadian-led sounding rocket every 3-5 years, in collaboration with other national agencies where possible,

(3) Fund participation in foreign-led collaborations at a rate of one every 1-2 years,

(4) Work to increase the number of Canadian groups involved in rocket research by encouraging and enhancing student recruitment and outreach,

(5) Consider rocket-borne testing of instruments destined for orbital missions but having no previous flight heritage, and

(6) Encourage collaboration between scientific disciplines within Canada, for example by combining mesospheric and ionospheric experiments in one payload where possible. Partnering with engineering departments should also be considered.

Finally, we note that the recommendations arising from this Workshop reinforce recommendations arising from previous community workshops. In particular, "*A Vision of Atmospheric Sciences for the Next 10 Years (2005-2015): The Report from the Atmospheric Environment (AE) Community 5th CSA – AE Workshop*", held in Banff in May 2005, included the following under the heading of **Enhancement of Development Processes for Advanced Studies and Satellite Missions**:

> ***Recommendation:*** *that the Small Payloads Program for balloons, aircraft, rockets, and micro-satellites be continued; and that there be the option of testing observing systems (in aircraft, balloons, rockets or ground-based platforms) for Satellite Missions, to enhance the reliability and operation of the system once in orbit. This could also positively affect the development and validation stages.*
>
> ***Discussion:*** *The* ***rationale*** *was for significant benefits to HQP* [highly qualified personnel] *training and science quality and penetration. This Small Payloads Program is vital for "small science", instrument development, training of HQP, and maintaining continuity in the Atmospheric Environment community, particularly if the community is to be limited to two larger satellite missions over the next decade. There is the possibility that the programmic-mechanism for the desired "testing" of systems could be achieved through the "small payloads" program.*

2. Workshop Overview

Attendance at the Workshop was excellent, with 85 registered participants, and about 80 of these able to be present. This is clear evidence of the strong interest in Canada in using suborbital platforms to pursue scientific exploration. The registrants included 11 graduate students, 13 postdoctoral fellows, 7 research associates, 17 professors, 8 representatives from industry, and 20 government colleagues. There was excellent representation from a range of organizations, including:

- Universities – Alberta, Calgary, Cambridge (UK), Dalhousie, Ecole Polytechnique de Montreal, Leibniz Institute of Atmospheric Physics (Germany), Lethbridge, Saskatchewan, Toronto including the Space Flight Laboratory, Université Pierre et Marie Curie (France), Waterloo, and York
- Industry – ABB Bomem, Bristol Aerospace Limited, COM DEV Ltd., Optech Incoporated, MPB Communications Inc., Resonance Ltd., Scientific Instrumentation Ltd., and Thoth Technology Inc.
- Government – Canadian Space Agency, Columbia Scientific Balloon Facility (USA), Communications Research Centre, Environment Canada, National Research Council, Natural Resources Canada, NASA Goddard Space Flight Center (USA), and NOAA Chemical Sciences Division (USA).

Appendix A provides a complete list of registrants.

On the first day of the Workshop, the program included the invited talks, contributed talks on past projects and case studies, and contributed talks on industrial capabilities and interests. The program began with an introductory plenary session, which included a *Workshop Introduction* *and Overview* (K. Strong), *Opening Remarks from the Canadian Space Agency* (D. Kendall), and *Opening Remarks from Environment Canada* (B. McArthur).

This was immediately followed by the plenary session on aircraft, with invited talks by Prof. Roderic Jones, Department of Chemistry, University of Cambridge, UK (*Atmospheric Research Using the New UK Research Aircraft*) and Dr. Adrian Tuck, Program Leader, Meteorological Chemistry Program, NOAA Chemical Sciences Division, USA (*Science Mission on Global Hawk*). The remainder of the aircraft session consisted of four contributed talks that covered the history of airborne collaborative research by Environment Canada and the National Research Council (W. Strapp), NRC's recent aircraft research activities involving cloud radar (M. Wolde), airborne atmospheric research at York University (J. Whiteway), and the use of suborbital measurements of tropospheric composition in the validation of chemical data assimilation studies (M. Parrington).

This was followed by the plenary session on balloons. Invited talks were given by Mr. David Pierce, Chief, NASA Balloon Program Office, USA (*Future of NASA Scientific Ballooning in Space and Earth Science Research*) and Dr. Albert Hertzog, Université Pierre et Marie Curie, Laboratoire de Météorologie Dynamique, Ecole Polytechnique, France (*The Contribution of Long-duration Balloon Flights in the Study of Stratospheric Dynamics: the Example of Strateole/Vorcore*). The five contributed talks included overviews of atmospheric measurements from balloons with MANTRA cited as a case study (K. Strong), and long-duration ballooning for astronomy/astrophysics with BOOMERANG and BLAST used as case studies (B. Netterfield). Balloon payload and flight support capabilities of Scientific Instrumentation Ltd were presented (D. Sommerfeldt), followed by an overview of balloon-borne infrared instruments flown by the University of Denver (P. Fogal), and a case study of a miniature optical sensor for measuring atmospheric trace gases (M. Wolff).

The last session of the day was the sounding rocket plenary, which began with invited talks by Dr. Robert F. Pfaff, Jr., NASA/Goddard Space Flight Center, USA (*Overview of the NASA Sounding Rocket Programm -- Unique Scientific and Technical Capabilities and Achievements*) and Prof. Dr. Franz-Josef Lübken, Director, Leibniz-Institute of Atmospheric Physics, Germany (*Sounding Rocket Investigations of the Polar Mesopause Region: Achievements and Perspectives*). The contributed talks included case studies of the Suprathermal Particle Imager (D. Knudsen), a prototype Langmuir probe for ICI-1 (J. Aase), and the Thermal Suprathermal Analyzer on the Japanese SS520-2 Rocket (A. Yau), as well as a history of Canada's Black Brant suborbital rocket (A. Legary).

In addition to the talks, posters were mounted on the morning of day one and remained up for the duration of the Workshop. Four posters described industrial capabilities and interests (F. Grandmont for ABB Bomem, J. Hahn for Optech, and two by D. Sommerfeldt for Scientific Instrumentation Ltd.). Three posters presented results from the MANTRA balloon campaigns (S. Melo, M. Toohey, D. Wunch), and one described prospects for developing balloon-borne *in situ* gas sensors using vertical-cavity surface-emitting lasers (A. Lytkine).

The day concluded with the Workshop Banquet, held at the Executive Dining Centre, Schulich School of Business, on the York University campus.

The focus of day two was the future, with a series of contributed talks on proposals for future projects, including five talks by graduate students and postdoctoral fellows on the topic of "If I Had a Million Dollars…". Possible aircraft missions included measurements of cirrus clouds (M. Earle, I. Grishin), high-altitude turbulence and *in situ* or remote chemical tracer measurements (M. Hegglin, A. Brown), combined lidar and *in situ* measurements and possibilities for testing instrument concepts (J. Whiteway). This was followed by an overview of Resonance's aircraft, balloon and rocket experience (B. Morrow), and a presentation on satellite validation and the relevance of suborbital measurements (J. Drummond). A proposal on how to structure a future balloon program, based on student experiences during MANTRA, was presented (D. Wunch, M. Toohey). Potential new atmospheric balloon missions included flights of the Argus instrument to monitor greenhouse gases (B. Quine), and PARIS-IR and a millimeter wave/sub-millimeter wave emission instrument (K. Walker). Looking further afield, talks were given on the Skycam tethered aerostat for deployment on the Inukshuk Mars rover (R. Kruzelecky), a balloon-borne planet finder and the uesfulness of zeppelins (M. van Kerkwijk), and the SPIDER mission, due for launch in 2009 to study cosmic microwave background B-modes (C. MacTavish). This portion of the Workshop concluded with a proposal for a sounding rocket mission to investigate cold ionospheric currents (J. Burchill).

In the afternoon, participants split into three break-out groups (for balloons, aircraft, sounding rockets), each tasked with reviewing current capabilities, new science and missions, infrastructure issues, and a vision for the future. Each break-out group was assigned a discussion leader (J. Whiteway for aircraft, B. Quine for balloons, and D. Knudsen for sounding rockets) and a reporter to record the highlights of the discussions (M. Hegglin for aircraft, K. Walker for balloons, and J. Burchill for sounding rockets). All participants were given a list of questions and topics to stimulate discussions, and these were grouped as follows.

Present Activities

- What is the present state of activity in Canada for each platform?
- What is the level of interest in flight opportunities for each platform in Canada?
- What are the opportunities for international collaboration? How can collaborations between Canadian universities, government agencies, and industry, and with international partners be created and enhanced?

New Science & Missions

- What are the major issues and new science questions that can be addressed with each platform?
- What new approaches, techniques, and technologies are being developed for each platform?
- How important is each platform for the development and testing of new instruments?
- Discuss activities, opportunities, and goals for the next ten years for each platform.
- What are the challenges?
- Identify a list of potential new missions.

Infrastructure

- What infrastructure is needed to enable new missions?
- How can this best be established?

- What are the relative merits of building and/or maintaining the Canadian capacity for balloon and rocket launches vs. contracting launches or piggy-backing on international missions?
- Is there is a need for a high-altitude aircraft platform within Canada, and if so, what are the performance requirements?
- Recommendations for what is needed to maintain continuity.

Vision
- Describe a ten-year vision for the Small Payloads Program.
- What should be done in the next year to begin to realise that vision?

At the conclusion of the break-out sessions, participants reconvened for a final plenary that included short reports from each of the three groups and some general discussion. The Workshop then came to a close, with some concluding remarks and thanks to all the participants.

Appendix B lists the schedule of events for the Workshop, and Appendix C provides internet links for the Workshop Proceedings, which includes all abstracts and presented talks and posters, as well as the summary presentations resulting from the three break-out sessions.

3. Report from the Aircraft Break-out Session

Participants

Discussion Leader: Jim Whiteway (York University)
Reporter: Michaela Hegglin (University of Toronto)
Section Author: Jim Whiteway (York University)

Anthony Brown (NRC), Mike Earle (University of Waterloo), Igor Grishin (University of Waterloo), Rod Jones (University of Cambridge), Dave Marcotte (NRC), Mark Parrington (University of Toronto), Walter Strapp (Environment Canada), Adrian Tuck (NOAA), Mengistu Wolde (NRC)

3.1 Background

As the most vital issues in atmospheric science concern the lower atmosphere, this region will be the focus of proposed CSA missions for remote sensing. The best platforms for accessing heights below 15 km are aircraft. It is then natural that aircraft will be applied for instrument development, validation, and advancing the scientific basis for CSA orbital missions.

There is an outstanding track record of scientific research with aircraft in Canada. Over recent decades, this work has been carried out mainly at the Flight Research Laboratory of the National Research Council (NRC). Of particular relevance to CSA is the partnership between Environment Canada and NRC for utilization of aircraft for atmospheric research. This was described in the Workshop presentation by Strapp *et al.* (11:15, day 1). The main theme of the discussion in the aircraft breakout session was to broaden the availability of the NRC aircraft for projects led by scientists at universities for research that is relevant to CSA missions. Application of the NRC aircraft was discussed with respect to several scientific issues.

3.2 Scientific Issues and Associated Aircraft Platforms

1. Upper Troposphere and Lower Stratosphere (UTLS)

The UTLS region is vital for the environmental issues of stratospheric ozone depletion and climate change. For example, the water in the anvil outflow from tropical convection can enter the stratosphere and be transported to the polar regions, where it forms the clouds that lead to ozone depletion. However, the fate of most of the water transported upward in convection is to remain in the troposphere and this is the strongest atmospheric feedback mechanism that will determine the magnitude of climate change. It is expected that there will be proposed instruments and missions that will focus on water in the UTLS region, dynamical transport, and associated chemical species.

Most of the discussion concerned the UTLS region since there has not previously been a sustained effort with aircraft within Canada for heights above 5 km. Atmospheric research in the UTLS region will require measurements in the 8 to 20 km height range. This means that advancement in UTLS research will require either new aircraft or a new application of the existing NRC aircraft. Various options were discussed for aircraft that can operate effectively to heights above 17 km. An example was given in the presentation by Adrian Tuck (10:15, day 1). Considering the limited time available, it was decided that the first step should be to consider utilization of the existing NRC aircraft.

The NRC has two aircraft that can operate in the UTLS region, and these were described in the presentation by Brown *et al.* (10:00, day 2). One of these is the T-33. It is a rugged military trainer aircraft with a ceiling of about 12.5 km. This is best suited for *in situ* measurements. It is currently instrumented for high-resolution turbulence measurements for wake-vortex studies. The other NRC aircraft capable of UTLS research is the Falcon-20. This also has a ceiling of about 12.5 km. It is a passenger aircraft with room for instrument operators. The Falcon is best suited for the installation of remote sensing instruments, such as lidars, that would most benefit the presence of an operator.

Possible UTLS measurement campaigns based on the NRC aircraft were discussed. These include the following.

a) Convection and transport in the tropopause region. Lidar systems on board the Falcon aircraft would be used to study the influenced of convection on the distribution of water vapour, and the generation of gravity waves and mixing at the tropopause. Flights would be conducted from Darwin, Australia, or Costa Rica for tropical convection. Flights would also be conducted from Northern Canada to study the transport of forest fire pollution that gets injected into the UTLS region by pyro-convection.

b) Cirrus clouds and effects of aircraft exhaust. The CT-33 would be equipped for measurements of turbulence, ice crystals, aerosol particles, water vapour. The goal would be to study the mechanisms of ice crystal formation and the influence of pollution such as aircraft exhaust.

c) Dynamics in the UTLS. Both aircraft would be applied to study long-range transport as well as small-scale mixing. Lidars on board the Falcon would measure the overall compositional structure of the UTLS region while the *in situ* measurements on board the CT-33 would provide small-scale structure. Flights over the Rocky Mountains would be used to study the influence of wave breaking. Flights from the NRC headquarters in Ottawa would be used to study wave and turbulence generation in the jet stream.

2. Tropospheric Pollution and Transport

In the presentation by Strapp *et al.* (11:15, day 1), it was demonstrated how the NRC Convair, and Twin Otter have been active in studies of pollution, with eleven major projects over the past decade. It is expected that the results of airborne pollution studies will be used to define future space missions, and that the NRC infrastructure will be used for validation.

3. Development of Instruments

The NRC Falcon will be especially useful for testing new instruments that measure in the UTLS region. An example is that there are plans utilize the NRC Falcon to test the SHOW instrument for measurements of water vapour (currently in development at York University). The instrument can view out of a window port with similar geometry to the orbital scenario. *In situ* measurements on board the aircraft would also be available for comparison.

4. Validation of Satellite Instruments

Aircraft are the natural platform for validating satellite remote sensing measurements in the troposphere. An example was given by Strapp *et al.* (11:15, day 1) and Wolde *et al.* (11:30, day 1) of the application of the NRC aircraft cloud measurements and this capacity has recently been utilized for validation of CloudSat. It is expected that the NRC CT-33 and Falcon will be used for validating instruments remote sensing of the UTLS region from orbit.

3.3 International Collaboration

There are many aircraft available in other countries that can be hired for scientific research projects. This would be necessary if *in situ* sampling was required at heights above 13 km. For example, the Egrett aircraft (from Airborne Research Australia) can operate at heights up to 15 km. This aircraft has been hired by York University and results from this work were shown in the presentation by Jim Whiteway (11:45, day 1). There are also possibilities for collaboration with such platforms as HIAPER (High-performance Instrumented Airborne Platform for Environmental Research), operated and supported by the National Science Foundation and the National Center for Atmospheric Research in the USA.

3.4 Planning

The long-term plan is to build up the investment in aircraft infrastructure that is available to universities. This has been achieved in other countries. An excellent example is the UK Facility for Atmospheric Measurements and this was presented by Professor Rod Jones (9:45, day 1).

The overall theme for planning was to develop stronger links between the NRC, CSA, and universities. A step in this direction is a proposal that is currently being planned for utilizing both the Falcon and CT-33 for atmospheric research. This will involve lidar systems installed on the Falcon for measurements of water vapour, ozone, clouds, and aerosol. The CT-33 will carry instruments for measurements cloud and aerosol particles, and chemical composition. So far this has been initiated in discussions involving York University, Environment Canada, and the NRC. There will be an effort to expand the collaboration to include contributions from CSA and other universities.

3.5 Recommendations

We recommend that the CSA:

(1) Include aircraft as platforms within the scope of the Small Payloads Program.

(2) Provide funding for the use of aircraft for instrument testing, characterization, and validation. This would include the costs of installation as well as the aircraft operations.

(3) Provide 20% matching funds for applications to the Canadian Foundation for Innovation (CFI) for aircraft infrastructure. This would include testing and characterization of instruments being developed for CSA missions.

4. Report from the Balloon Break-out Session

Participants

Discussion Leader: Ben Quine (York University)
Reporter: Kaley Walker (University of Toronto)
Section Author: Kimberly Strong (University of Toronto)

Names of participants were not recorded. At least 30 people took part in this session, resulting in the participants moving back into the auditorium, as there was insufficient seating in the break-out room.

4.1 Background

Canada has a long history of scientific ballooning, dating back to airglow measurements made in 1960. Early efforts were led by the Canadian Armament Research and Development Establishment, the University of Saskatchewan, and the National Research Council (NRC). A series of pioneering measurements were made through the 1960s and 1970s, including measurements of hydroxyl emission and the 1.27-micron O_2 band. A variety of early instrumentation was flown, including infrared spectrometers, Michelson interferometers, and filter photometers. Launches were made from a variety of locations, including Valcartier, Saskatoon, Yorkton, Gimli, and Churchill. NRC established and maintained launch capabilities until the mid-1980s, when these were transferred to Environment Canada, who moved NRC launch support equipment from Gimli to Vanscoy, Saskatchewan, and contracted Scientific

Instrumentation Ltd. (SIL) to run the balloon base there. SIL has had balloon launch capability since 1987, and has done 200 flights, 110 of these from Vanscoy and others from Alert, Eureka, Churchill, North Bay, and Roleau.

In the 1970s and 1980s, the Atmospheric Environment Service of Canada led the Stratoprobe series of balloon flights that included measurements of NO_2 and HNO_3 that predate the onset of stratospheric ozone depletion. These campaigns contributed to our understanding of the stratosphere and included early estimates of the northern hemisphere mid-latitude odd-nitrogen budget. The more recent MANTRA (Middle Atmosphere Nitrogen TRend Assessment) series of four high-altitude balloon flights, which carried instruments to measure vertical concentration profiles of a suite of stratospheric trace gases, built on these earlier Stratoprobe efforts. The first MANTRA launch, in 1998, was the first Canadian large high-altitude balloon mission in 15 years, and was followed by three more late summer campaigns, in 2000, 2002, and 2004, all conducted at Vanscoy, with payload and launch support provided by Scientific Instrumentation Limited.

Meanwhile, Canada has also become an active participant in a number of high-profile international astronomy balloon missions, such as BOOMERANG and BLAST, both launched by NASA/CSBF. BOOMERANG carried a millimeter-wave telescope to measure anisotropies in the cosmic microwave background, and included two test flights in Palestine, Texas in 1997, with long-duration flights (10-12 days) from McMurdo, Antarctica in 1998 and 2003. BLAST carried a sub-millimeter telescope to map the interstellar medium and determine star formation rate evolution. A test flight was undertaken at Palestine in 2003, with science flights from Kiruna, Sweden in 2005, and McMurdo in 2006.

We are now at a critical juncture with regard to future ballooning activities in Canada. Environment Canada is reconsidering its support of the launch facility at Vanscoy, and much of the existing payload and launch support equipment there dates back 20-30 years. As noted in Bruce McArthur's opening remarks to the Workshop:

- *"The present facility is inadequate to meet any long-term high-altitude balloon programs.*
- *Environment Canada does not have the resources necessary to re-develop the facility without partners.*
- *Scientists within EC recognize that research opportunities exist under the EC mandate to fully utilize such a facility should the appropriate partnerships develop."*

We need to decide whether Canada should maintain its own payload support and launch capability or rely on contracting launches to organizations such as CSBF (Columbia Scientific Balloon Facility, formerly the National Scientific Balloon Facility in the United States) or CNES (Centre National d'Etudes Spatiales in France). Without access to regular flight opportunities, it is difficult to build and maintain these capabilities. There are also questions about the trade-off between flight risk and resources. As currently implemented, ballooning is not supported and managed as a space program in Canada, where risk avoidance is key. Moving to a risk avoidance model where all systems are fully flight-tested will require an increase in resources, and is likely to move some development out of universities and reduce student involvement. One model is to involve engineers who accompany a project and advise the students in their work; through such professional involvement the success of a campaign can be better guaranteed.

4.2 Present state of activity in Canada

Table 1 lists balloon missions over the past twelve years having Canadian involvement. There have been only two Canadian-led balloon mission in that period (MANTRA and BAM), although Canada has also been a key participant in two international astronomy missions (BOOMERANG and BLAST). The first two MANTRA flights were selected under the CSA's First Small Payloads Program, while the following two MANTRA flights were selected under the CSA's Second Small Payloads Program. MANTRA was also supported by the Meteorological Service of Canada (all flights), CRESTech (1998), and NSERC (2002, 2004). Environment Canada continues to have an active small balloon program, typically launching 70 radiosondes daily, as well as weekly ozonesondes, and some tethered balloon experiments.

Table 1 – Balloon missions with Canadian participation

Mission	**PI Institute**	**Partners**	**Science objectives**
Balloon-borne Anisotropy Measurement (BAM) 1995, 1998	UBC (M. Halpern)	University College London	Characterization of fluctuations in the cosmic microwave background
MANTRA 1998, 2000, 2002, 2004	U Toronto (K. Strong)	Environment Canada (C.T. McElroy, EC Lead Scientist), York U, U Waterloo, U Denver, CNRS Service d'Aéronomie	Odd-nitrogen budget of the northern hemisphere mid-latitude stratosphere
BOOMERANG 1998, 2003	Caltech (A. Lange) and U Rome (P. deBernardis)	U Rome I, CalTech, U Toronto (B. Netterfield, Co-I), JPL, Cardiff U, CWRU, IROE-CNR	Anisotropies in the cosmic microwave background
BLAST 2005, 2006	U Penn (M. Devlin)	U Toronto (B. Netterfield, Co-I), Brown U, UBC (M. Halpern, Co-I), U Miami, Cardiff U, JPL, INOE (Mexico)	Map the interstellar medium and determine star formation rate evolution
Radiosondes; Ozonesondes; Tethered balloons	Environment Canada		70 daily radiosondes for meteorology; weekly ozone-sondes for ozone profiles; tethered balloons for surface characteristics and radiative and chemical properties of the lower troposphere

Analysis of data from some of these missions is continuing, but many peer-reviewed papers have already been published. For example, more than a dozen papers have resulted from BOOMERANG, and several of these have had a major impact on the field of cosmology. Another dozen papers have been published on MANTRA, including seven in a special issue of *Atmosphere-Ocean*, and several others submitted or in preparation for a 2007 special issue of *Atmospheric Chemistry and Physics*.

Ballooning is an excellent means for providing training, offering students (and others involved) the opportunity to participate in all stages of an experiment from concept to hardware, measurements, and data analysis. They receive training in quality control and risk management, hands-on experience deploying instrumentation in the harsh near-space environment, field operations, team projects, technical skills associated with launching stratospheric balloons, and experience in handling manageable data sets from a field experiment, often in collaboration with other members of the science team. As proof of this, one has only to look at the backgrounds of space scientists; nearly every principal investigator of a Canadian satellite instrument has worked on high-altitude balloon missions.

All of the large balloon missions shown in Table 1 have had significant involvement from students and postdocs. A total of five BSc, nine MSc, and eight PhD theses involving the MANTRA campaigns are either completed or in progress. More than 25 undergraduate research students participated in the project, along with eight postdocs and research associates, ten technical personnel, and additional engineering and technical personnel at Scientific Instrumentation Limited. Between BLAST and BOOMERANG, five PhDs have been completed, with nine more in progress, along with involvement by approximately ten undergraduates and six postdocs.

4.3 New science questions that can be addressed by balloons

Balloon platforms offer excellent opportunities for scientific exploration in fields ranging from atmospheric chemistry and dynamics, radiation, weather, and climate, to astronomy and astrophysics. They are particularly well suited to atmospheric observations, enabling observations of detailed atmospheric processes at much higher spatial and temporal resolution than is possible from the ground or from satellites. They have also proven to be ideal for certain astrophysical observations from above the atmosphere, particularly as long-duration flight capabilities have developed. Balloons can carry a variety of payloads, including sampling, *in situ*, and remote sounding instruments, ranging in size from a few kilograms to several tons. They can fly at altitudes from near the surface to the upper stratosphere, reaching near-space conditions at float altitudes of 40 km. The duration of balloon flights can range from a few hours to several weeks, and they can be designed for special flights to match scientific requirements, such as valve-controlled slow descent, long and ultra-long duration flights, and tethered flights.

NASA's Scientific Ballooning Roadmap Report (October 2005, see Appendix C for full reference) describes how ballooning has been a major contributor to NASA's science program, and makes clear the extent to which balloon-borne instruments will continue to play a major role in an array of missions dealing with the exploration of the universe, cycles of matter and energy in the universe, Sun-solar system connections, and Earth observations. For example, from page 21:

> The May 2005 *Strategic Roadmap for Earth Science and Applications (Strategic Roadmap #9)* acknowledges the importance of balloons: "NASA's atmospheric composition research program also requires essential suborbital and laboratory measurements, as well as a vigorous modeling effort. Suborbital observations obtained by instruments on board balloons, manned aircraft, and unmanned aerial vehicles (UAVs), provide validation of satellite measurements as well as definition of processes occurring on spatial and temporal scales that are challenging to observe from space."

The following are examples of key science questions of interest to Canadian scientists that might be addressed by balloons.

Atmospheric Science Questions:

- How and why is the chemical composition of the atmosphere changing?
- How will changes in atmospheric composition affect stratospheric ozone, climate, and global air quality?
- What is the impact of climate change on future stratospheric ozone depletion, particularly in the Arctic?
- What is the polar stratospheric bromine budget?
- What are the fine-scale microphysical processes that create polar stratospheric clouds?
- What is the impact of forest fires on the global atmosphere?
- What is the vertical and horizontal distribution of water vapour?
- How well can we quantify the Earth's radiation budget – the balance between downwelling solar radiation and upwelling terrestrial radiation?
- What is the radiative impact of aerosols?
- What is the structure, composition, and transport of high-level aerosols in outflow layers? What are the impacts for chemistry? How can the combination of observations with models help answer these questions?
- What are the sources and sinks of greenhouse gases?
  (Balloons can be used to sample different scenes, validate upcoming greenhouse gas satellite missions, provide accurate vertical structure information, and feed these data into improving models.)
- How can biomass observations be combined with models to develop and improve vegetation canopy lidar scattering models?
- What is the global distribution of day-time and night-time stratospheric vector wind profiles? (Here, ballooning could contribute to the Chinook/SWIFT mission through validation and correlative measurements.)
- What is the true vertical structure of the atmosphere?
- How can we probe the atmosphere at better vertical resolution than we do now?
  (For example, on ascent and through improved occultation and limb scanning – this implies higher temporal resolution, more frequent flights.)

Astrophysics Science Questions:

- Are there other planets that could support life?
- Is our solar system and our planetary system unique?
- What is the physics that describes the earliest hottest densest time of the universe?
- When did the first stars form?
- Where did the initial matter density fluctuations come from?
- Why is the universe so smooth?

4.4 Importance in the development and testing of new instruments

Balloons provide an invaluable platform for testing new instruments in the near-space environment, enabling the assessment of their suitability for satellite missions. These prototypes can later be used for validation and trouble-shooting of the satellite instruments and for complementary measurements, providing close synergy between balloon and satellite missions. It should be noted that balloon flights feed into space missions in several ways, through developing and strengthening science, technology, expertise, and personnel. The time-scales for balloon missions are relatively short, typically taking from one to five years from concept to flight. For example, the MAESTRO instrument on Canada's SCISAT-1 mission evolved from Environment Canada's SunPhotoSpectrometer; both it and a balloon version of MAESTRO (MAESTRO-B) flew on the MANTRA campaigns prior to the launch of SCISAT-1.

MANTRA provides an example of the use of balloon platforms for technology development. Four new instruments were first flown during the MANTRA campaigns: an acousto-optical tunable filter spectrometer, MAESTRO-B, an adaptation of the SCISAT-1 ACE-FTS instrument called PARIS-IR, and an airglow infrared radiometer. In addition, a new pointing control system was developed, and a ground-based UV-visible grating spectrometer was deployed during the balloon campaigns, enabling the evaluation of NO_2 vertical profile retrievals by comparison with the balloon measurements. Several other instruments were refurbished or rebuilt for the MANTRA flights, and new retrieval algorithms were developed for the analysis of the resulting data: infrared emission radiometers, a Bomem DA5 Fourier transform spectrometer, the aforementioned SunPhotoSpectrometers, a Bomem DA2 FTS from the University of Denver, and an OH spectrometer.

Similarly, on the cosmology side, BOOMERANG's balloon-borne millimeter-wave telescope demonstrated technology now used for the Planck Satellite, while the BLAST sub-millimeter telescope used the receiver from the SPIRE instrument on Herschel. NASA's Scientific Ballooning Roadmap Report provides many additional examples of space instrumentation that developed from balloon flights, ranging from all the instruments on the Compton Gamma Ray Observatory to MLS, TES, and HIRDLS on NASA's current EOS-Aura mission, and to instrumentation on the Mars Polar Lander.

4.5 New balloon technologies

There are many new technologies being developed for future balloon missions. These include improvements and innovations in:

- Pointing system accuracy
- Communications, including high-speed data links
- Autonomy – improvements in system operation
- Flight duration
- Super-pressure balloons
- UV-resistant balloon materials
- Trajectory control – overpressure, controlled in height, zeppelins, aerobots (steerable)
- Power systems
- On-board storage
- Detector technologies – continuous improvement occurring in this area
- Modular payload – structure, systems
- Differential GPS – depends strongly on satellite orientation
- Launch techniques
- Being able to access "know-how"

With recent advances in these technologies, the capabilities and reliability of scientific ballooning continue to improve, making novel scientific investigations possible. In particular, significant effort is being put into the development of ultra-long duration balloon (ULDB) flights. The primary challenge for achieving such flights is the diurnal temperature cycle. During the day, solar heating causes the gas inside the balloon to expand, which can make it necessary to release gas to avoid floating too high. During the night, the cooling and resulting contraction of the gas requires the release of ballast to maintain altitude. Flight duration is thus limited by the availability of ballast and gas.

There are three types of long duration balloons currently in use. The first are the more traditional zero-pressure balloons that have been successfully used in long duration flights in the polar regions. For example, the 2004 Cosmic Ray Energetics And Mass (CREAM) flight recently set a flight duration of 41 days and 22 hours, circumnavigating the South Pole three times in Antarctic summer, when constant daylight allowed the float altitude to remain relatively stable at 37 to 40 km. NASA/CSBF is also developing large (600,000 m^3) superpressure balloons to carry heavy payloads to high altitudes, with the goal being to carry 1600 kg to 35 km for flights up to 100 days. These are sealed spherical ("pumpkin-shaped") balloons, made of durable composite plastic and fabric materials that can withstand high pressure during the day, and maintain pressure at night. Meanwhile, CNES has successfully developed and flown small superpressurized balloons that can carry payloads of 10-20 kg at altitudes of 18-20 km for several months; balloons have been flown over the Arctic, Antarctic, and equatorial regions, for the Strateole/Vorcore campaigns. A third balloon design is that of the Montgolfiere Infra-Rouge (MIR), also developed by CNES; these consist of two separate hemispheres that allow the balloon to be heated by sunlight during the day and by upwelling infrared fluxes during the night. More than 40 such flights have been conducted, typically carrying a 60-kg payload to 18-22 km at night and to 28 km during the day; flights last about three weeks on average, but have been known to circumnavigate the globe three times over 69 days.

Looking further to the future, a number of proposals have been made for the deployment of global networks of hundreds of balloons for that would remain aloft for several years, making Earth observations that would complement those by satellites. These include the Global Air-ocean IN-situ System (GAINS) and the StratoSat™ constellation. Additional concepts include aerobots – steerable helium-filled blimps with possible landing and floating capabilities, which are of particular interest for planetary exploration, and the AEROCLIPPER. This is a small balloon that floats at about 50 m, in or just above the boundary layer; it is connected to a cable that is in contact with the surface of the ocean and is capable of covering long distances over several weeks for simultaneous sea surface and atmospheric boundary layer measurements.

4.6 Level of interest in balloon flight opportunities

In both the Canadian atmospheric science and astrophysics communities, the level of interest in balloon flight opportunities is very high. In addition to the junior and senior scientists who have graduated from or worked on the MANTRA, BOOMERANG, and BLAST projects, there is also interest from other Canadian scientists, as evidenced from the attendance at the Workshop and the large number of participants in the balloon break-out session. However, for people to invest significant time and effort in planning and developing new balloon experiments, there must be some reasonable expectation of regular, reliable flight opportunities.

One proposal made at the Workshop (by current and former graduate students who worked on MANTRA) was to split launches into two streams, as outlined in Table 2 below. There was some discussion of this idea, but it was not universally endorsed. Any new program structure must enable the development of major new instrumentation or measurement concepts.

Table 2 - One Model for a Dual-Stream Balloon Program

Flagship Stream	**Development Stream**
Primary goal: scientific • Satellite validation • Atmospheric chemistry/dynamics • Astrophysics	Primary goal: instrument development and HQP training Secondary goal: scientific
Must have previously proven performance • Examples: the JPL MkIV Balloon Interferometer, MAESTRO, PARIS-IR (eventually)	Treated as student project
Treated as a satellite program • Appropriate budget • Strict milestones and scientific deliverables • Frequent launches of these flagship payloads (i.e. at least once per year)	Long-term goal: develop a flagship instrument

4.7 Opportunities for international collaboration

There are major opportunities for international collaboration in ballooning. This has already been demonstrated with the success of BOOMERANG and BLAST, which are both large collaborative efforts that have involved multiple institutions from a number of countries (USA, Italy, UK, Mexico), with launches provided by NASA and CSBF. While MANTRA was Canadian-led, it also included partners from the USA and France.

It is important that Canada enter international collaborations as an equal partner, contributing resources appropriately, and pulling our weight more so than we have. Timely funding mechanisms are also critical to enable successful participation in international missions when the opportunities arise.

Representatives from NASA (David Pierce) and CSBF (Danny Ball) were present at the Workshop. They made it clear that NASA and CSBF are open to collaborations, and offered to meet with CSA personnel to discuss how the agencies might work together effectively. For example, they noted that there are opportunities to piggy-back launches on scheduled balloon flights, as well as providing dedicated launches. Piggy-back payloads require flexibility and must meet the constraints of the primary launch, but offer another option for flying smaller instruments. There are also possibilities for collaboration with other international ballooning groups, as well as with other launch partners, such as CNES, which is also interested in developing international collaborations.

4.8 Relative merits of building and/or maintaining the Canadian capacity for balloon launches versus purchasing launches or piggy-backing on international missions.

The advantages of Canadian-led balloon launches include:
- Maintaining Canada's technical capabilities
- Allowing Canadian PI's to determine scientific goals and launch conditions
- Providing opportunities to fly and test unproven, higher-risk payloads
- Supporting Canadian industry, and providing students and postdocs with opportunities for interaction with industry

Weighed against this are issues of finances, availability, and reliability. Collaborating with international partners can be financially advantageous, and has worked very successfully for the astronomy community. The cost of a dedicated NASA/CSBF balloon launch is on the order of several $100,000, which is comparable to costs within Canada.

The atmospheric community has a long tradition of Canadian-led and launched balloon missions, but our launch capabilities have not been maintained. Ideally, a new program would support both approaches, collaborating with international launch partners for large balloon missions and sharing expertise, hardware, and launch sites, but also establishing and maintaining a Canadian launch facility for small to mid-sized payloads. Scientific Instrumentation Ltd. currently runs the balloon base at Vanscoy, and has indicated that it is interested in continuing to do so. The cost of upgrading the existing infrastructure there ranges from an absolute minimum of $100,000-

200,000 for the purchase of some essential new equipment, to something much higher, depending on the scale of the new facility that is envisioned. A more realistic budget to properly redevelop the facility is probably $1-2M.

What infrastructure is needed to enable new missions?

Balloon infrastructure includes two major components: (1) facilities for the development, building, and testing of new instrumentation, and (2) facilities for payload integration, launch, and recovery, which includes supporting systems such as power, telemetry, and pointing.

Instrument development can be done in industry and in universities, if the facilities are available. The latter is preferable to maximize the training of students and postdocs. Astronomy estimated that $0.5-1M /year could be spent on instrument development. The relatively new High Bay in the Department of Astronomy and Astrophysics at the University of Toronto was built specifically for the development and hanging tests of new balloon payloads. Thermal and vacuum testing of instrumentation can be performed at the U of Toronto Space Instrument Characterization Facility, and at the new CRESS (Centre For Research in Earth and Space Science) Space Instrumentation Laboratory at York University.

With regard to launch infrastructure, new astronomy missions involve long-duration flights, typically using balloons of 40 million cubic feet (mcf). These require the launch capabilities of CSBF, or the equivalent, which would need a major investment of new resources to establish in Canada. The astronomy community anticipates having one very heavy launch every other year or so. This combination of infrequent launches and heavy payloads is well served by CSBF, and so upgrading the Canadian launch capability to include such large missions is not a priority for the astronomy community.

For atmospheric scientists, new science can be accomplished with a range of payloads, from small packages weighing tens of kg to MANTRA-type payloads of 600-700 kg, which were launched with 11.6-mcf balloons. A typical atmospheric science payload might consist of two instruments and a pointing system, would weigh about 200 kg, giving a strawman total payload mass of about 500 kg. Scientific Instrumentation Ltd's current maximum rating is for 3500-lb (1600 kg) payloads and 20-mcf balloons. It was noted that CNES is encouraging reduction in the size of experiments, typically launching 100-140 kg payloads 3-4 times per year, with an upper limit of 300-400 kg. Hand launches can be done for payloads of up to 45-50 kg.

If we are to establish and maintain a Canadian launch facility for small to mid-sized payloads, this will require a significant investment in launch support equipment, either at Vanscoy or elsewhere. This might also involve enabling a deployable launch facility. As experience with MANTRA has shown, reliability is critical to the scientific success of balloon missions, with the number of launches being a strong determinant. There is thus a strong argument for ensuring that multiple launches per year take place for the weight level supported by an upgraded facility.

As noted above, Environment Canada, which currently manages the balloon base at Vanscoy, *" does not have the resources necessary to re-develop the facility without partners"*. However, EC does have an interest in making full use of a new facility, if it could be developed under some partnership arrangement. EC's Atmospheric Science and Technology Directorate (ASTD) made the following commitment at the Workshop (presentation by B. McArthur):

- *"To ensure that those programs to which we commit, we bring the funding necessary to be full partners throughout the life of the project."*

And also stated that:

- *"ASTD will work with our partners (CSA, universities, OGDs, industry) in whatever ways possible to support atmospheric research using these platforms."*

NASA and CSBF stated at the Workshop that they would be willing to help CSA (and other partners) re-invigorate the Canadian balloon program. In addition, A. Hertzog indicated that CNES may be interested in using the Vanscoy facility in the future for some of its large balloon campaigns.

4.9 Vision for the future

Our ten-year vision is to have a strong, reliable balloon program that contributes to scientific exploration, instrument development, and training of the next generation of scientists. This program would engage Canadian universities, government agencies, and industry, and would consist of a minimum of two Canadian-led flights per year for ten years, both within Canada and with international partners. It would have the flexibility to support both riskier new instruments as well as proven ones, to take advantage of flights of opportunity at short notice, and to enable the development and implementation of new balloon technologies and capabilities, thereby leading to greater opportunities for new and exciting scientific missions.

Balloons offer great potential to investigate and answer fundamental scientific questions. To that end, our goals for the next decade include:

- Establishing an active and sustainable ballooning program, with yearly (or more frequent) flight opportunities
- Creating large Canadian-led projects, with international collaborators
- Building and maintaining the student experience, giving students and postdocs as much responsibility as possible
- Involving engineers and technicians to provide expertise and continuity to projects
- Contributing to the space program through instrument development and spin-offs for space science and space technology
- Testing most future satellite instruments on balloon platforms, prior to their deployment in space
- Achieving a Canadian long-duration balloon flight capability
- Establishing an Arctic launch capability, with the possibility of circumpolar flights
- Building a deployable launch capability that can provide access to both hemispheres

A number of challenges were also identified, and need to be addressed in order to achieve the goals and vision stated above:

- The current absence of a balloon program
- Infrequent flight opportunities

- Lack of reliability of our existing infrastructure, which has resulted in system and launch failures
- The ability to undertake quicker re-flights
- Funding the development of new instruments
- A Canadian ballooning facility for long-duration flights would require agreements with Russia to allow over-flights of Russian territory
- Personnel issues, on both the technical and scientific sides, including the stability of funding and of positions
- Managing contracts, funding, reporting, and team co-ordination for large and small projects
- Multi-agency co-ordination
- Data archiving – astronomy has this in place, atmospheric science does not, although some efforts are underway

4.10 Recommendations

The importance of balloons in advancing science, developing and testing new instrumentation, validating satellite measurements, and training future scientists is widely recognized. The relevance of ballooning to space science is clear from the significant investments that space agencies such as NASA and CNES have made, and continue to make, in their balloon programs. The future of scientific ballooning in Canada will depend on the level of investment that we make in people, instrument development, new technologies, flight opportunities, launch capabilities, and international partnerships.

To enable the ten-year vision stated above to become a reality, we recommend that the CSA:

(1) Establish and maintain a Canadian-led stably-funded, long-term (10-year) balloon program, with regular flight opportunities, enabling a minimum of two flights per year. An active, ongoing program supporting several overlapping balloon projects at different stages would require a budget of at least $1M per year.

(2) Provide a mechanism for funding international opportunities as they arise, facilitating this in a timely manner. For example, flights of opportunity may well have timelines on the order of 3 to 6 months. If we are to take advantage of such opportunities, then CSA must be able to review and fund them in a time frame that may be on the order of a few weeks to a few months in advance.

(3) Fund the development of new instrumentation.

(4) Ensure that there is support for balloon flights of both new higher-risk instruments as well as well-proven ones.

(5) Provide strong support for test flights of future satellite instruments on balloon platforms, prior to their deployment in space.

(6) Actively support the involvement of students, postdocs, and younger scientists in ballooning.

(7) Have realistic expectations for the management of large and small projects by university-based investigators.

(8) Undertake multi-agency co-ordination of support for missions, insofar as possible.

(9) Give consideration to leveraging of CFI or other funding in the upcoming Small Payloads Program Announcement of Opportunity.

(10) Support the community's efforts to achieve new Canadian capabilities, such as a long-duration balloon flight capability, an Arctic launch capability, and/or a deployable launch capability.

(11) Arrive at an agreement leading to the upgrade or replacement of the launch support infrastructure at Vanscoy, in partnership with Environment Canada.

In addition, those present at the balloon break-out session agreed that further discussion of this last issue was needed. Kaley Walker volunteered to organize a follow-on planning meeting for balloon community, where we can discuss, in more detail, what should be done over the next year to begin to realise the ten-year vision stated above. If CSA and EC are unable to arrive at an agreement, as in recommendation #11, then alternative options for consideration include:

(i) preparing a CFI proposal to invest in and rebuild the balloon base, with CSA, EC, and industry participation;
(ii) having CANDAC (the Canadian Network for Detection of Atmospheric Change) take charge of upgrading and then operating the balloon base;
(iii) having an industry-led initiative to create a world-class facility capable of doing launches for international missions; and
(iv) closing the facility and moving to international partnerships for launches.

A last recommendation is thus that:

(12) The Canadian ballooning community reconvene to make a coherent plan with firm recommendations regarding the future of Canadian launch capabilities.

5. Report from the Sounding Rocket Break-out Session

Participants

Discussion Leader: David Knudsen (University of Calgary)
Reporter: Johnathan Burchill (NRCan)
Section Author: David Knudsen (University of Calgary)

Johnny Aase (University of Calgary), Rebecca Batchelor (University of Toronto), Andrea Legary (Bristol Aerospace), H. Gordon James (CRC Ottawa) Denis Laurin (CSA), Laureline Sangalli (University of Calgary), Andrew Yau (University of Calgary)

Other contributors

Robert Pfaff (NASA/GSFC), Bill Morrow (Resonance Inc.)

5.1 Background

Canadian sounding rocket research began with the construction of the Churchill Rocket Range (CRR) for the International Geophysical Year, reaching a peak of several Canadian launches per year in the mid 1970's. Launch frequency then diminished until the closure of the CRR in 1984. Since that time, Canada has been involved sporadically with rockets launched from foreign ranges, with the exception of one launch from CRR in 1998.

The decades-long burst of rocket activity in Canada produced a modest number of students, due in part to the fact that much of the research was carried out in government labs having little or no graduate student involvement. As a result, the number of Canadian researchers carrying out sounding rocket research today is quite small. However, student involvement has been on the rise since the transfer of the space plasma instrumentation group from the National Research Council/Herzberg Institute of Astrophysics to the University of Calgary in 1995. This trend must continue if Canada is to have highly-qualified instrument scientists to support the ambitions of its long-term space plan.

5.2 Present state of activity in Canada

Table 3 lists scientific sounding rocket missions over the past twelve years having Canadian involvement. There have been only three Canadian-led sounding rocket missions in the past twelve years, the most recent being in 2000.

Nevertheless, as Table 3 shows, Canada has remained active in sounding rocket research, in large part through foreign flight opportunities.

Table 3 – Sounding rockets with Canadian participation

Mission	PI Institute	Canadian instruments	Science objectives
OEDIPUS-C, Nov 1995	CRC Ottawa	HEX/REX (CRC); MAG/LP (Magnametrics Ottawa); TID/EED (Calgary)	Stimulated and natural plasma waves and wave-particle interactions
ACTIVE Apr 1998		TPA (Calgary); Photometer (Saskatoon)	Ionospheric distribution functions
GEODESIC, Feb 2000	Calgary	SII/TEI (Calgary); MAG (Magnametrics)	Auroral plasma waves and particle acceleration
SS520-2	ISAS/Tokyo	TSA (Calgary)	Cusp ion acceleration
Cusp2002 Dec 2002	NASA GSFC	SEI/SII (Calgary)	Cusp electrodynamics, plasma waves, and particle acceleration
JOULE Mar 2003	Clemson U.	SII (Calgary)	Structured Joule heating
JOULE-II Jan 2007	Clemson U.	SII (2 instruments) (Calgary)	Structured Joule heating with AMISR radar support
S-520 Jul 2007	ISAS/Tokyo	SII (Calgary)	Low-latitude IT coupling

All past rockets shown in Table 3 have had significant involvement from students and/or postdocs. While analysis of data from most of these missions is continuing, scientific accomplishments to date include thirty peer-reviewed scientific publications (twenty-five from OEDIPUS-C alone), along with two prominent international dissertation awards, underscoring the fact that sounding rockets provide stand-alone scientific value as well as essential training opportunities.

5.3 New science questions that can be addressed by sounding rockets

Sounding rockets are the only viable platform for studies of the mesosphere, and of the lower ionosphere and thermosphere (with the exception of "diving" satellites.) Sounding rockets are optimally suited to study micro-scale physics at altitudes up to 1500 km, and possibly higher with next-generation vehicles. In the past ten years, novel experiments have been designed to resolve space-time ambiguity through multiple sub-payloads, and to study point-to-point wave propagation studies through the use of tethered sub-payloads, for example.

The following are examples of outstanding science questions of interest to Canadian scientists that can be (or are being) addressed by sounding rockets:

- Direct measurement of auroral return currents through thermal electron drift (c.f. workshop presentation by Johnathan Burchill, 12:45, day 2)
- Direct detection of parallel electric fields responsible for low-altitude auroral electron acceleration
- Expanded studies of low-altitude field-aligned plasma flow in the ionosphere
- *In situ* observation of auroral wave generation and propagation in the ionosphere (e.g. auroral roar)
- Vertical and horizontal structure of ion-neutral coupling and Joule heating in the lower ionosphere/thermosphere (e.g. JOULE I/II)
- Reconciliation of mesospheric atomic oxygen measurements from different techniques,
- Continuous measurement of gases (e.g. O, OH, O_3, NO, H_2O, H, Cl, ClO, Br) from the mesosphere through to the lower stratosphere through the use of parachutes

5.4 Importance in the development and testing of new instruments

As with any new experimental technique, multiple design iterations are required to develop space instruments into cutting-edge research tools. While some iterations can be accomplished through laboratory testing, instruments (and instrumentalists) must eventually be proven and improved through actual flights. Experience in Canada has shown that even "small" satellites take 5-10 years to develop and launch, whereas sounding rocket flights allow new ideas to be vetted within 1-2 years of approval, meaning they are much better suited to rapid improvements in instrument design.

The discrepancy between rocket and satellite development times can be reduced with more frequent and regular satellite opportunities (e.g. QuickSAT). Still, sounding rockets are the only appropriate platform for some measurements, and the most appropriate for others.

5.5 Future prospects

Canada should continue its participation in international collaborations along the lines of those carried out in the past two decades. *However, Canada must take its turn leading such missions.*

The technical capability to build payloads in Canada resides primarily with Bristol Aerospace, who have indicated that they continue to have both the interest and the infrastructure to carry out this type of work. One-off, custom-built payloads of the type used for OEDIPUS-C and GEODESIC cost upwards of $2M, not including instruments and motors. In the past, Bristol have indicated that the cost per launch could be reduced considerably if Canada could guarantee 1-2 launches per year. However, an informal survey in 2001 indicated that there are not enough scientists in Canada carrying out rocket-based research to support this level of activity. Still, the one-off missions of the past decade have proved to be highly valuable both scientifically and in terms of student training, and are much more economical than orbital missions.

5.6 New rocket technologies

Recent technological advances that could be used in the next generation of rocket experiments include:

- Reusable rocket vehicles
- High-altitude (>3000 km), long-range (>1000 km) vehicles
- Standardized interfaces
- Trajectory shaping
- High bandwidth telemetry
- Precision attitude control
- Miniaturized multiple sub-payloads and instrumentation

5.7 Level of interest in sounding rocket flight opportunities

While the number of Canadian scientists interested in sounding rocket experiments in Canada is currently low, the interest among them is high.

5.8 Opportunities for international collaboration

Canada maintains active collaborations with the USA and Japan, and has received expressions of interest from Norway and France. International collaborations have been the mainstay of Canada's space plasma instrumentation program for decades, and it is hard to imagine a viable future space science program without this component.

In the past, international collaborations led by foreign institutes have been funded in Canada through unsolicited proposals to the CSA. CSA has recently indicated that all future proposals must be in response to AO's from the Agency. This will require that AO's must come frequently (at least once per year), and/or that development be funded for instruments that have no identified flight opportunity, so that they will be ready when an opportunity does come.

5.9 Relative merits of building and/or maintaining the Canadian capacity for rocket launches versus purchasing launches or piggy-backing on international missions.

The advantages of Canadian-led rocket launches include:

- Maintaining Canada's technical capabilities in rocket payload and vehicle development
- Allowing Canadian PI's to determine scientific goals and launch conditions
- Providing opportunities to fly and test unproven, higher-risk designs

On the other hand, piggy-backing on international missions has an obvious and significant cost advantage. A sustainable program requires both approaches, which is to say a collaboration in which Canada both benefits from and contributes to an international resource pool. While past collaborations have been worked out in an ad-hoc basis, Canada should explore ways to formalize relationships in which technical and scientific expertise, vehicle and payload hardware, and launch venues can be shared.

5.10 Recommendations

The role of sounding rockets in developing new instruments and in training new experimentalists is self-evident. The future vitality of Canada's *in situ* space science program depends less on the magnitude of the funding allocated than on a clear and predictable plan to continue sounding rocket research. We recommend that CSA:

(1) Maintain and enhance Canada's ability to participate in international collaborations by i) ensuring sufficiently frequent and regular AO's, ii) forming or supporting working groups with both agency-level and scientist-level participation to develop bilateral collaborations in specific disciplines, and iii) weighing carefully the decision no longer to accept unsolicited proposals, which have been the mainstay of Canadian participation in international space science missions and scientific instrumentation programs for decades,

(2) Fund a Canadian-led sounding rocket every 3-5 years, in collaboration with other national agencies where possible,

(3) Fund participation in foreign-led collaborations at a rate of one every 1-2 years,

(4) Work to increase the number of Canadian groups involved in rocket research by encouraging and enhancing student recruitment and outreach,

(5) Consider rocket-borne testing of instruments destined for orbital missions but having no previous flight heritage, and

(6) Encourage collaboration between scientific disciplines within Canada, for example by combining mesospheric and ionospheric experiments in one payload where possible. Partnering with engineering departments should also be considered.

6. Concluding Remarks

This Workshop on Science from Suborbital Vehicles strongly supports an ongoing Small Payloads Program, with a regular series of AOs capable of simultaneously supporting aircraft, balloon, and sounding rocket missions. There is sufficient interest in all three platforms that each could easily use the nominal SPP budget of $1-2M per year. Spreading this budget over all three platforms and six scientific disciplines will make it difficult to maintain continuity and expertise in any one of them. With the limited number of upcoming Canadian space missions (e.g., Chinook and possibly one other mission in the next decade in atmospheric environment), the role of a reinvigorated Small Payloads Program becomes even more critical in building and maintaining expertise in our universities and industry. The interest of Canadian companies in suborbital missions is clear from the attendance of industrial representatives at the Workshop. Further evidence is seen in the letters of support provided in Appendix E.

Our overall ten-year vision for suborbital missions is to establish an active and viable small payloads program whose importance in contributing to scientific exploration, instrument development, and training is recognized at CSA and in the wider community. This program would engage Canadian universities, government agencies, and industry, and would consist of regular flight opportunities for all three platforms. It would have the flexibility to support flights of both new and proven instruments, to enable the development and implementation of new technologies and capabilities, thereby leading to greater opportunities for new and exciting scientific missions.

7. Thanks

It was encouraging to see such a strong turn-out at the Workshop, proof of our community's interest in suborbital missions. The Workshop successfully brought together participants with a wide range of interests (scientific, technical, commercial) and backgrounds (academic, industrial, government, international) and led to interesting and productive discussions.

On behalf of the community and all attendees, we would like to thank the Canadian Space Agency for supporting this Workshop and kindly providing the funds needed to make it happen. Particular thanks are due to Rejean Michaud, Stella Melo, Thomas Piekutowski, and David Kendall. We would also like to thank Environment Canada for so kindly providing their excellent facilities for our use, with special thanks to Walter Strapp, David Tarasick, and Bruce McArthur for help with on-site arrangements.

We were fortunate to have had six outstanding invited speakers attend the Workshop: Albert Hertzog, Roderic Jones, Franz-Josef Lübken, Robert F. Pfaff, David Pierce, and Adrian Tuck. They travelled from France, Germany, the United Kingdom, and the United States to join us. We thank them for so generously contributing their time, effort, and expertise to our enterprise. Their talks provided us with insight into suborbital activities underway in other countries, and showed what can be achieved if the necessary interest, will, and resources are available.

Thanks are also due to all the session chairs, discussion leads, and reporters, who worked hard to keep the Workshop running smoothly and right on schedule over both days. In addition, the following people provided invaluable assistance with logistics both before, during, and after the Workshop: Rebecca Batchelor, Annemarie Fraser, Ana Sousa, Tobias Kerzenmacher, and Mareile Wolff.

As Chair of the Organizing Committee, I would like to thank all the Committee members for their assistance in planning, running, and reporting on the Workshop.

Finally, thank-you to everyone who attended and contributed so enthusiastically to the Workshop, taking time from your busy schedules to contribute to this important effort. We all hope that the recommendations arising from our discussions will have a positive impact on the future of suborbital missions in Canada.

Appendix A. List of Registrants

#	Last Name	First Name	Organization	Email	Status	Talk or Poster
1	Aase	Johnny	University of Calgary	aase@phys.ucalgary.ca	Research Associate	yes
2	Ball	Danny	Columbia Scientific Balloon Facility	Danny.Ball@csbf.nasa.gov	Other	
3	Batchelor	Rebecca	University of Toronto	rbatchelor@atmosp.physics.utoronto.ca	Postdoc	
4	Birner	Thomas	University of Toronto	thomas@atmosp.physics.utoronto.ca	Postdoc	
5	Brown	Anthony P.	NRC	Anthony.Brown@nrc-cnrc.gc.ca	Other	yes
6	Bourassa	Adam	University of Saskatchewan	adam.bourassa@usask.ca	Grad Student	
7	Burchill	Johnathan	Natural Resources Canada	jburchil@nrcan.gc.ca	Postdoc	yes
8	Degenstein	Doug	University of Saskatchewan	doug.degenstein@usask.ca	Professor	
9	Drummond	James	Dalhousie University	james.drummond@dal.ca	Professor	yes
10	Earle	Mike	University of Waterloo	meearle@scimail.uwaterloo.ca	Grad Student	yes
11	Fogal	Pierre	University of Toronto	pierre.fogal@utoronto.ca	Research Associate	yes
12	Fraser	Annemarie	University of Toronto	amery@atmosp.physics.utoronto.ca	Grad Student	
13	Grandmont	Frédéric	ABB Bomem	frederic.j.grandmont@ca.abb.com	Industry	yes
14	Grishin	Igor A.	University of Waterloo	igrishin@scimail.uwaterloo.ca	Postdoc	yes
15	Hahn	John	Optech Incoporated	jfrederickh@hotmail.com	Industry	yes
16	Haley	Craig	York University	cshaley@yorku.ca	Research Associate	
17	Hegglin	Michaela I.	University of Toronto	michaela@atmosp.physics.utoronto.ca	Postdoc	yes
18	Hertzog	Albert	Université Pierre et Marie Curie	albert.hertzog@lmd.polytechnique.fr	Research Associate	yes
19	Hudak	David	Environment Canada	David.Hudak@ec.gc.ca	Government	
20	Hum	Robert H.	Consultant	r.hum@sympatico.ca	Other	
21	Jagpal	Rajinder	York University	jagpal@yorku.ca	Grad Student	
22	James	Gordon	Communications Research Centre	gordon.james@crc.ca	Government	
23	Jones	Roderic	University of Cambridge	rlj1001@cam.ac.uk	Professor	yes

24	Jonsson	Andreas	University of Toronto	andreas@atmosp.physics.utoronto.ca	Research Associate	
25	Kendall	David	Canadian Space Agency	dave.kendall@space.gc.ca	Government	yes
26	Kerzenmacher	Tobias	University of Toronto	tobias@atmosp.physics.utoronto.ca	Postdoc	
27	Knudsen	David	University of Calgary	knudsen@phys.ucalgary.ca	Professor	yes
28	Kruzelecky	Roman V.	MPB Commun-ications Inc.	roman.kruzelecky@mpbc.ca	Industry	yes
29	Kuhn	Thomas	University of Waterloo	tkuhn@uwaterloo.ca	Postdoc	
30	Laurin	Denis	Canadian Space Agency	denis.laurin@space.gc.ca	Government	
31	Legary	Andrea	Bristol Aerospace Limited	andrea.legary@magellan.aero	Industry	yes
32	Lindenmaier	Rodica	University of Toronto	rodica@atmosp.physics.utoronto.ca	Grad Student	
33	Liu	Peter	Environment Canada	peter.liu@ec.gc.ca	Government	
34	Liu	William	Canadian Space Agency	william.liu@space.gc.ca	Government	
35	Loewen	Paul	CANDAC	prl242@gmail.com	Other	
36	Lübken	Franz-Josef	Leibniz Institute of Atmospheric Physics	luebken@iap-kborn.de	Professor	yes
37	Lytkine	Alexandre	University of Alberta	alytkine@ualberta.ca	Research Associate	yes
38	MacTavish	Carrie	University of Toronto	cmactavi@cita.utoronto.ca	Postdoc	yes
39	Marcotte	Dave	National Research Council, Canada	david.marcotte@nrc-cnrc.gc.ca	Government	
40	McArthur	Bruce	Environment Canada	Bruce.McArthur@ec.gc.ca	Government	yes
41	McDade	Ian	York University	mcdade@yorku.ca	Professor	
42	McElroy	Tom	Environment Canada	tom.mcelroy@sympatico.ca	Government	
43	McLandress	Charles	University of Toronto	charles@atmosp.physics.utoronto.ca	Research Associate	
44	McLinden	Chris	Environment Canada	chris.mclinden@ec.gc.ca	Government	
45	Melo	Stella M.L.	Canadian Space Agency	stella.melo@space.gc.ca	Government	yes
46	Midwinter	Clive	University of Toronto	clive.midwinter@gmail.com	Other	
47	Morrow	Bill	Resonance Ltd.	bmorrow@resonance.on.ca	Industry	yes

48	Netterfield	Barth	University of Toronto	netterfield@astro.utoronto.ca	Professor	yes
49	Nowlan	Caroline	University of Toronto	cnowlan@atmosp.physics.utoronto.ca	Postdoc	
50	Parrington	Mark	University of Toronto	mark.parrington@utoronto.ca	Postdoc	yes
51	Pfaff	Robert, F., Jr.	NASA Goddard Space Flight Center	Robert.F.Pfaff@nasa.gov	Government	yes
52	Piekutowski	Thomas	Canadian Space Agency	thomas.piekutowski@space.gc.ca	Government	
53	Pierce	David	NASA Goddard Space Flight Center	David.L.Pierce@nasa.gov	Government	yes
54	Qin	Guoying	University of Toronto	gqin@atmosp.physics.utoronto.ca	Grad Student	
55	Quine	Brendan	York University and Thoth Technology	ben@thoth.ca	Professor	yes
56	Rahnama	Peyman	COM DEV Ltd.	Peyman.Rahnama@comdev.ca	Industry	
57	Roberts	Caroline	Thoth Technology Inc.	caroline@thoth.ca	Industry	
58	Sangalli	Laureline	University of Calgary	sangalli@phys.ucalgary.ca	Grad Student	
59	Schofield	Ian	University of Lethbridge	ian.schofield@uleth.ca	Other	
60	Seth	Raj	York University	rajseth@yorku.ca	Grad Student	
61	Shepherd	Gordon	York University	gordon@yorku.ca	Professor	
62	Shepherd	Marianna G.	York University	mshepher@yorku.ca	Professor	
63	Shepherd	Ted	University of Toronto	tgs@atmosp.physics.utoronto.ca	Professor	
64	Silicani	Marc	Ecole Polytechnique de Montreal / CSA	Marc.Silicani@space.gc.ca	Other	
65	Sioris	Chris	Environment Canada	christopher.sioris@ec.gc.ca	Postdoc	
66	Sloan	Jim	University of Waterloo	sloanj@uwaterloo.ca	Professor	
67	Solheim	Brian	York University	bsolheim@yorku.ca	Other	
68	Sommerfeldt	Dale	Scientific Instrumentation Ltd	dale.sil@shaw.ca	Industry	yes (3)
69	Strapp	J. Walter	Environment Canada	walter.strapp@ec.gc.ca	Government	yes
70	Strawbridge	Kevin	Environment Canada	Kevin.Strawbridge@ec.gc.ca	Government	

71	Strong	Kimberly	University of Toronto	strong@atmosp.physics.utoronto.ca	Professor	yes
72	Tarasick	David	Environment Canada	david.tarasick@ec.gc.ca	Government	
73	Taylor	Jeffrey	University of Toronto	jeff@atmosp.physics.utoronto.ca	Grad Student	
74	Toohey	Matthew	University of Toronto	mtoohey@atmosp.physics.utoronto.ca	Grad Student	yes (2)
75	Tuck	Adrian F.	NOAA Chemical Sciences Division	Adrian.F.Tuck@noaa.gov	Government	yes
76	van Kerkwijk	Marten	University of Toronto	mhvk@astro.utoronto.ca	Professor	yes
77	Walker	Kaley	University of Toronto	kwalker@atmosp.physics.utoronto.ca	Professor	yes
78	Walker	Anne	Environment Canada	anne.walker@ec.gc.ca	Government	
79	Whiteway	Jim	York University	whiteway@yorku.ca	Professor	yes (2)
80	Wolde	Mengistu	National Research Council	mengistu.wolde@nrc.gc.ca	Government	yes
81	Wolff	Mareile	University of Toronto	mwolff@atmosp.physics.utoronto.ca	Postdoc	yes
82	Yan	Peifeng	University of Toronto	pyan@atmosp.physics.utoronto.ca	Grad Student	
83	Wunch	Debra	University of Toronto	debra@atmosp.physics.utoronto.ca	Postdoc	yes
84	Yau	Andrew	University of Calgary	yau@phys.ucalgary.ca	Professor	yes
85	Zee	Robert E.	Space Flight Laboratory, UTIAS	rzee@utias-sfl.net	Other	

Appendix B. Schedule of Events

Thursday, February 1							
Chair	**Start**	**End**	**Duration**	**Session**	**Name**	**Theme**	**Title**
	8:30	9:00	30	Coffee & Refreshments			
Strong	9:00	9:15	15	Opening Plenary	Strong	Opening	Workshop Introduction and Overview
Strong	9:15	9:30	15	Invited Talk	Kendall	Opening	CSA Perspective
Strong	9:30	9:45	15	Invited Talk	McArthur	Opening	EC Perspective
Strapp	9:45	10:15	30	Invited Talk	Jones	Aircraft	Atmospheric research using the new UK research aircraft
Strapp	10:15	10:45	30	Invited Talk	Tuck	Aircraft	Science Mission on Global Hawk
	10:45	11:15	30	Posters / Refreshments	**See list below**		
Hudak	11:15	11:30	15	Past / Case Studies	Strapp	Aircraft	Three decades of airborne collaborative research by Environment Canada and the National Research Council of Canada.
Hudak	11:30	11:45	15	Past / Case Studies	Wolde	Aircraft	NRC Airborne Cloud Radar Capability and Recent Research Activities
Hudak	11:45	12:00	15	Past / Case Studies	Whiteway	Aircraft	Airborne atmospheric research at York University
Hudak	12:00	12:15	15	Past / Case Studies	Parrington	Aircraft	Utilization of suborbital measurements of tropospheric composition in the validation of chemical data assimilation studies
	12:15	1:15	60	Lunch			
Degenstein	1:15	1:45	30	Invited Talk	Pierce	Balloons	Future of NASA Scientific Ballooning in Space and Earth Science Research
Degenstein	1:45	2:15	30	Invited Talk	Hertzog	Balloons	The contribution of long-duration balloon flights in the study of stratospheric dynamics: the example of Strateole/Vorcore
Degenstein	2:15	2:30	15	Past / Case Studies	Strong	Balloons	Probing the Atmosphere from Balloon Platforms
Degenstein	2:30	2:45	15	Past / Case Studies	Netterfield	Balloons	Long Duration Ballooning
Degenstein	2:45	3:00	15	Industrial capabilities/interests	Sommerfeldt	Balloons	Balloon payload and flight support
Degenstein	3:00	3:15	15	Past / Case Studies	Fogal	Balloons	Balloon-borne Infrared Spectrometer Systems Operated by the University of Denver
Degenstein	3:15	3:30	15	Past / Case Studies	Wolff	Balloons	PIOS: a miniature optical sensor for measuring atmospheric trace gases
	3:30	4:00	30	Posters / Refreshments	**See list below**		
James	4:00	4:30	30	Invited Talk	Pfaff	Rockets	Overview of the NASA Sounding Rocket Programm -- Unique Scientific and Technical Capabilities and Achievements
James	4:30	5:00	30	Invited Talk	Lübken	Rockets	Sounding rocket investigations of the polar mesopause region: achievements and perspectives
James	5:00	5:15	15	Past / Case Studies	Knudsen	Rockets	Development of the Suprathermal Particle Imager and the Role of Sounding Rockets
James	5:15	5:30	15	Industrial capabilities/interests	Legary	Rockets	The History of Canada's Black Brant Suborbital Rocket
James	5:30	5:45	15	Past / Case Studies	Aase	Rockets	Development of a prototype Langmuir probe for the ICI-1 sounding rocket
James	5:45	6:00	15	Past / Case Studies	Yau	Rockets	Case Study of a Hitch-hiker: The Thermal Suprathermal Analyzer (TSA) Instrument on the Japanese SS520-2 Rocket
	6:00			End			

Friday, February 2							
Chair	**Start**	**End**	**Duration**	**Session**	**Name**	**Theme**	**Title**
	8:30	9:00	30	Coffee and Refreshments			
Marcotte	9:00	9:15	15	If I Had a Million Dollars	Earle	Aircraft	A New Approach for Observing Ice Crystal Habit in Model Cirrus Clouds
Marcotte	9:15	9:30	15	If I Had a Million Dollars	Grishin	Aircraft	Image Processing Method for Retrieving Ice Crystal Habits in Cirrus Clouds
Marcotte	9:30	9:45	15	If I Had a Million Dollars	Hegglin	Aircraft	The dream of a Canadian high-altitude research aircraft ...
Marcotte	9:45	10:00	15	Proposals	Brown	Aircraft	NRC High Altitude Atmospheric Research Aircraft
Marcotte	10:00	10:15	15	Proposals	Whiteway	Aircraft	Proposed airborne atmospheric research at York University
Marcotte	10:15	10:30	15	Past/Case Studies & Proposals	Morrow	All 3	Resonance's Aircraft, Balloon and Rocket Payloads, Past and Future
Marcotte	10:30	10:45	15	Past / Case Studies	Drummond	Balloons	What is Validation Anyway?
	10:45	11:15	30	Posters / Refreshments	**See list below**		
Netterfield	11:15	11:30	15	If I Had a Million Dollars	Toohey/Wunch	Balloons	If I had $1M
Netterfield	11:30	11:45	15	Proposals	Quine	Balloons	Argus Suborbital Flights
Netterfield	11:45	12:00	15	Proposals	Walker	Balloons	Something old and something new: PARIS-IR and beyond
Netterfield	12:00	12:15	15	Proposals	Kruzelecky	Balloons	Skycam Tethered Aerostat for the Inukshuk Landed Rover Canadian Mission to Mars.
Netterfield	12:15	12:30	15	Proposals	van Kerkwijk	Balloons	A Balloon Borne Planet Finder
Netterfield	12:30	12:45	15	Proposals	MacTavish	Balloons	SPIDER: A Balloon-Borne Polarimeter for Measuring Large Angular Scale CMB B-Modes
Netterfield	12:45	1:00	15	If I Had a Million Dollars	Burchill	Rockets	If I had a million dollars: In search of cold ionospheric currents
	1:00	2:00	60	Lunch			
	2:00	3:30	90	Break-out sessions	Leads & Reporters: Whiteway & Hegglin, Quine & Walker, Knudsen & Burchill	Break-out	
	3:30	4:00	30	Refreshments			
Strong	4:00	4:15	15	Report from aircraft session	Whiteway & Hegglin	Plenary	
Strong	4:15	4:30	15	Report from balloon session	Quine & Walker	Plenary	
Strong	4:30	4:45	15	Report from rocket session	Knudsen & Burchill	Plenary	
Strong	4:45	5:30	45	General discussion		Plenary	
	5:30			End			

POSTERS			
Industrial capabilities/interests	Grandmont	Balloons/ Aircraft	Suborbital instrument projects at ABB Bomem
Industrial capabilities/interests	Hahn	Balloons	High-altitude Balloon Flights as a Test and Operations Platform for Lidar Systems
Past / Case Studies	Lytkine	Balloons	PROSPECTS OF DEVELOPING BALLOON-BORNE GAS SENSORS BASED ON LONG-WAVELENGTH VCSELS FOR IN SITU CHEMICAL ANALYSIS OF THE ATMOSPHERE
Past / Case Studies	Melo	Balloons	BrO and NO2 measurements during the MANTRA 2004 campaign: comparisons with co-located ACE and ENVISAT satellite measurement.
Industrial capabilities/interests	Sommerfeldt	Balloons	Science using balloons
Industrial capabilities/interests	Sommerfeldt	Balloons	Space Science Engineering
Past / Case Studies	Toohey	Balloons	Observing nitrogen in the stratosphere: connecting present and past
Past / Case Studies	Wunch	Balloons	MANTRA, Turnaround, and the University of Toronto's Balloon-Borne Fourier Transform Spectrometer

Appendix C. Related Documents

Workshop Homepage

http://www.atmosp.physics.utoronto.ca/~workshop/

Workshop Program Book

(2.2 MB, 64 pages, includes background material, logistics information, schedule of events, and all abstracts)
http://www.atmosp.physics.utoronto.ca/~workshop/CWSSV_final_program.pdf

Workshop Proceedings

(48 MB, 583 pages, includes all abstracts and presented talks and posters, as well as the summary presentations resulting from the three break-out sessions)
http://www.atmosp.physics.utoronto.ca/~workshop/CWSSV_proceedings.pdf

NASA's Scientific Ballooning Roadmap Report

NASA Stratospheric Balloons: Pioneers of Space Exploration and Research. Preliminary Report of the Scientific Ballooning Planning Team. NASA NP-2006-3-754-GSFC, 44 pp. October 2005. This "roadmap" is intended to be updated and formally published by mid-2007.
Available online at http://sites.wff.nasa.gov/balloons/

Appendix D. Completion of Contract Tasks

The following tasks were specified under the CSA/PWGSC Contract (# 07/7003886) issued in support of the Workshop:

- Assemble an Organizing Committee, to include representation from relevant communities: balloon/aircraft/rockets, and atmospheric environment/space environment/astronomy.
- Choose a date for the Workshop that minimizes conflicts with other meetings and campaigns.
- Prepare a First Announcement, with a Call for Abstracts, and circulate it widely.
- Set up a Workshop homepage with web-based abstract submission and registration forms
- Invite guest speakers, who will provide a balance between technical advances and scientific exploration. Our preference will be for international speakers, insofar as possible.
- Prepare and circulate a Second Announcement.
- Prepare the Workshop program, incorporating abstracts for oral and poster sessions.
- Complete final arrangements for the Workshop (e.g., organizational structure, name tags, poster boards, refreshments, etc.)
- Hold the Workshop.
- Prepare a Workshop Report.
- Submit the Workshop Report for approval by CSA.
- Make the Report and Proceedings accessible for one year via the U of Toronto web site and communicate the web site address to the Canadian Atmospheric Scientific Community.

With the delivery of this Final Report, these tasks have been completed, following the schedule summarized in the table below. The last task will be done after the Report is approved by CSA.

MILESTONE (all complete)	**DATES**
Assemble the Organizing Committee	August-September 2006
Choose the date for the Workshop	October 2006
Prepare the First Announcement, with a Call for Abstracts, and circulate it widely (released November 23)	October-November 2006
Set up the Workshop homepage	November 2006
Invite guest speakers	November-December 2006
Prepare and circulate a Second Announcement (released January 5, 2007)	December 2006
Deadline for abstract submission and registration	Friday, January 12, 2007
Prepare the Workshop program, incorporating submitted abstracts for oral and poster sessions (released January 30, 2007)	January
Complete final arrangements for the Workshop	Late January
Hold the Workshop	February 1-2, 2007
Submit the Workshop Report	March 31, 2007

Expenditures under the Contract remained within budget, and funds were used as intended, for:

(i) travel and living expenses of the invited international guest speakers,

(ii) travel and living expenses of graduate students, postdoctoral fellows, and research associates, and

(iii) direct costs, including rental of poster boards, refreshments, printing of the program, and miscellaneous costs associated with organizing and holding the Workshop.

Financial reporting will be done by Research Services, University of Toronto.

Appendix E. Letters of Support from Industry

1. ABB Bomem Inc.
2. Bristol Aerospace Ltd.
3. COM DEV Ltd.
4. Continuum Aerospace Inc.
5. MPB Communications Inc.
6. Optech Incoporated
7. Picomole Instruments Ltd.
8. Resonance Ltd.
9. Scientific Instrumentation Ltd.
10. Thoth Technology Inc.

ABB

Quebec City, 20 March, 2007

Dr. Kimberly Strong, Professor
Department of Physics, University of Toronto
Room MP 710A, 60 St. George Street
Toronto, Ontario, M5S 1A7, Canada

Object: Letter of Support for Suborbital Missions

Dear Prof. Strong,

Thank you very much for inviting ABB to the Suborbital Workshop on Science from Suborbital Vehicles, which was held in Toronto on February 1 and 2. As you know, ABB (formerly known as Bomem) has a strong heritage of sub-orbital missions, the first project of its history having been a balloon-borne FT-IR built in the 70's. Subsequent missions, such as the MANTRA flights, have involved several instruments built by ABB and we are very proud of collaborating on the success of these balloon missions.

We are thus writing this letter of interest and support for future suborbital missions, especially those related to balloon-borne or airborne validation campaigns and scientific experiments. Over the years, it became clear that suborbital missions are very important in validating satellite programs and creating new ideas of science. Balloon-borne programs are therefore pathfinders for new science as well as powerful tools for validation and calibration of other instruments.

Consequently, please do not hesitate to contact us for any request of support.

Marc-André Soucy
Director, Remote Sensing industry
ABB

Jacques Giroux
Marketing Remote Sensing
ABB

MAGELLAN
AEROSPACE CORPORATION

BRISTOL AEROSPACE LIMITED

P.O. Box 874 · 660 Berry Street · Winnipeg, MB · Canada · R3C 2S4

March 26, 2007

Dr. Kimberly Strong
Department of Physics
University of Toronto Room MP 710A, 60 St.
George Street
Toronto, Ontario, M5S 1A7
Canada

Dr. Strong,

Bristol Aerospace Limited offers our support to the Canadian Suborbital Vehicles Community in their quest for increased and continued funding from the Canadian Space Agency.

Since the 1960s Bristol worked closely with the science community to developed more than 120 sounding rocket payloads for Canadian suborbital missions. These missions supported hundreds of post-graduate theses as well as investigations by Canadian scientists and researches in several space science fields.

Sounding rocket missions offer the ability to take measurements at altitudes between the minimum altitude of satellites and the maximum altitude of balloons. They allow scientists to conduct experiments at a time and place of their choosing. A typical sounding rocket mission spans two to three years from announcement of opportunity to launch and data collection, which is much faster than a typical satellite mission. In addition, compared to the complexity and cost of a satellite mission, sounding rockets provide relatively low cost access to space.

Bristol still holds the interest, expertise and the technical capability to provide engineering and payload services to support a Canadian Sounding Rocket Program. The Black Brant rocket system is in production in support of NASA's sounding rocket program, and Bristol qualified a new meteorological rocket called Excalibur that offers similar performance to Viper III. Bristol's engineering capability to design and develop payloads is also still intact.

We look forward to working with the Canadian Suborbital Vehicles Community as they plan for future missions.

Yours truly,

David O'Connor
Director of Defence and Space
Bristol Aerospace Limited

Continuum Aerospace
Powering a new age of spaceflight

Dr. Kimberly Strong
Professor
University of Toronto
Room MP 710A, 60 St. George Street
Toronto, Ontario, M5S 1A7

Michael Viechweg
Continuum Aerospace Inc.
Co-CEO
12 Bonnacord Drive
Toronto, Ontario, M3H 3G5
T 1 (416) 723-3093
mikev@continuumaerospace.com
www.continuumaerospace.com

Date 3/26/07

Dear Dr. Strong,

Thank you for your efforts in putting together the Suborbital Workshop on Science from Suborbital Vehicles on February 1st and 2nd of this year. Continuum Aerospace is presently working in collaboration with Ryerson University to develop rocket propulsion that represents a new standard in cost-effectiveness, rapid deployability, and environmental soundness, of relevance to both suborbital and orbital missions.

We believe strongly that support for suborbital missions and associated technology within Canada has become increasingly important in recent years as the the research community increasingly struggles to find dedicated, cost-effective, and rapidly deployable platforms close to home. We know that Canada has the knowledge and technical expertise to meet the challenges it face, however support from the CSA stands to play a decisive role. We would like to emphasize a point that was made at the workshop, that for our own company as well as for the broader scientific and technical community, sub-orbital missions can provide not only high intrinsic value, but also provide an important bridge and testing ground for orbital efforts. By engaging a broad cross-section of Canadian academia and aerospace industry, CSA can facilitate immediate achievements in suborbital science while supporting home-grown propulsion and related expertise important for launching eventual Canadian-based orbital missions.

Those of us in Canada's industrial and research communities are increasingly realizing that while collaboration with other countries will always play an important role, Canadian satellite missions right now pay a premium to foreign launch providers in order to be shoe-horned into sub-optimal platforms with lengthy lead times. It appears that more countries are recognizing the importance of supporting their domestic suborbital (and by extension orbital) capabilities within industry as a way of becoming intellectually and economically competitive and independent in this new age of space exploration. With appropriate support Canada need not fall behind.

Sincerely yours,

Michael Viechweg, P. Eng.
Co-CEO
Continuum Aerospace Inc.

COM DEV
SPACE

COM DEV Ltd.
155 Sheldon Drive
Cambridge, Ontario
Canada N1R 7H6
Tel: (519) 622-2300
Fax: (519) 622-1691

March 27, 2007

Dr. Kimberly Strong, Professor
Department of Physics, University of Toronto
Room MP 710A, 60 St. George Street
Toronto, Ontario, Canada. M5S 1A7
Phone: 1-416-946-3217 Fax: 1-416-978-8905
Email: strong@atmosp.physics.utoronto.ca

Subject: Letter of Support for the Suborbital Missions Program

Dear Kim,

COM DEV Ltd. is pleased to provide the suborbital community with this letter of support for the suborbital missions program. COM DEV has a keen interest in supporting development activities with the suborbital community, the Canadian Space Agency, Environment Canada and participating industry members.

While global measurements can only be made using satellite instruments, the suborbital missions have many advantages for the science and industrial communities. Suborbital missions contribute to scientific investigation, instrument development, and training of the next generation of scientists and engineers. The suborbital missions program will also enhance and create new collaborations between Canadian universities, government agencies, and industry.

COM DEV has extensive experience in space science instrumentation and some of the many programs/instruments we have worked on for the CSA include CPA, TPA, FUSE, WINDII, MOPITT, MAESTRO, SWIFT and CEFI. The CEFI instrument that we are working on for ESA's Swarm mission came out of the suborbital program work that Dr. Dave Knudsen at the university of Calgary was involved in.

COM DEV wishes the suborbital community and the CSA the best of luck in this program and we look forward to employing our expertise and experience to work with the suborbital community to develop new ideas and innovative instruments, which will hopefully lead to new satellite missions.

Sincerely, T. Girard.

Terry Girard
Business Development Manager
Space Electronics and Instruments
COM DEV

COMMUNICATIONS, INC

March 22, 2005

Dr. Kimberly Strong, Professor
Department of Physics, University of Toronto
Room MP 710A, 60 St. George Street
Toronto, Ontario, M5S 1A7, Canada

Dear Professor Strong,

MPBC is a medium sized company with currently about 100 employees and an R&D group totalling 30 personnel of which 15 have Ph.D.s. Our focus is on leading edge technologies and products in photonics and space systems.

As you are aware, MPB's R&D group in Space and Photonic Systems conducts leading edge research in miniaturization technologies for space systems; focusing on smart materials, photonics and fiber optics.

We are currently developing various miniature IR spectrometer systems and fiber-optic sensors towards potential missions such as the MEOS microsatellite for Earth Observation, as well as the Skycam aerostat blimp and miniature chemical analysis lab for the Inukshuk planetary exploration.

The suborbital balloon platform is a relatively low-cost means of validation and optimization for both measurements and the corresponding instruments for future usage in space from orbital platforms.

Moreover, the manouverable aerobot blimp platform is an attractive future vehicle for flexible planetary exploration, unhindered by terrain irregularities. It is also a good match for our miniaturization sensor technologies. It can also have significant terrestrial applications for natural resiurce management.

For these reasons, we strongly support your efforts with respect to the continued development of balloon platforms for sub-orbital studies. We would encourage a smaller controllable blimp that could be provided with a programmable navigation to enable validation of potential space missions over selected targets and routes.

I hope that your proposal will be received favorably and that our university-industry collaboration can further develop in the future.

Yours sincerely,

Dr. Roman V. Kruzelecky
Senior Research Scientist
MPB Communications Inc.

Optech

300 Interchange Way ▪ Vaughan, ON ▪ Canada L4K 5Z8 ▪ tel: 905 660 0808 ▪ fax: 905 660 0829 ▪ web: www.optech.ca

16 March 2007

Dr. Kimberly Strong, Professor
Department of Physics, University of Toronto
Room MP 710A, 60 St. George Street
Toronto, Ontario
M5S 1A7

Re: Support for suborbital missions

Dear Dr. Strong,

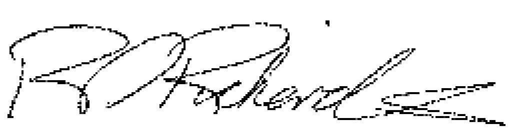
I would like to express strong support for the expanded utilization of suborbital missions as platforms for scientific exploration and innovation. Our Canadian owned and operated company has enjoyed over 30 years of growth in the Canadian high technology sector and has made significant investments in space and terrestrial technologies that are supporting Canada's reputation as a country of world class scientists and engineers. From and industrial/technical perspective, suborbital systems provide opportunities for economical rapid prototyping, proof of concept and system validation. When the prospect of good science is combined it is a winning proposition that engages multidisciplinary efforts.

When combined with innovative thinking and environmental concerns, suborbital missions provide inspiration to Canadian youth to pursue high tech careers while providing a context and understanding of why science and technology is important to their everyday lives. From the perspective of our developing space sector, suborbital rockets provide opportunities for student space scientists and engineers to engage in valuable work that is affordable and accessible within the context of most university graduate and undergraduate programs.

Encouraging increased Canadian focus on suborbital missions for science and technology innovation is a great idea and will no doubt become a valuable resource to a number of synergistic governmental, academic and industrial communities who otherwise do not have many opportunities to work together.

We applaud your efforts and strongly support the concept of suborbital missions as platforms for scientific exploration and innovation.

Sincerely,



Dr. Robert D. Richards
Director, Space Division

picomole
INSTRUMENTS INC

780.238.6429
www.picomole.com

suite 117, mailbox 26
advanced technology centre
9650 20 avenue NW, edmonton, AB,
canada, T6N 1G1

March 15, 2007

Prof. Kim Strong
Department of Physics
University of Toronto
60 St. George Street
Toronto, ON M5S 1A7

Dear Dr. Strong:

We are very pleased to offer our enthusiastic and heartfelt support for the suborbital science program in Canada. Suborbital science has a long and distinguished history in Canada, and this excellent program should be strongly supported by all levels of government.

Suborbital missions are an important method of testing and validating technologies that will eventually be deployed in space. The scientific data from such missions provide unique insights into atmospheric processes and validate space-borne instruments. Equally important, suborbital missions also provide a cost-effective means of training the next generation of experimental scientists. The technical and logistical challenges that have to be met for successful suborbital science missions create unparalleled practical opportunities for learning that simply cannot be replaced.

As you know, we have personally benefited from the opportunities for participation in suborbital science in the Department of Physics at the University of Toronto. Our company, Picomole Instruments Inc., is presently designing powerful trace gas analyzers that could be very useful to atmospheric scientists. Being able to deploy our instruments on future Canadian suborbital payloads could provide researchers with valuable information on atmospheric trace gases. These data would be useful for tracking the flow of pollution, greenhouse gases, and ozone depleting compounds.

We applaud your efforts to increase support for suborbital missions. If we can be of any further assistance, do not hesitate to ask.

Best regards,

John Cormier, PhD
Founder and CEO
Picomole Instruments Inc.

Denis Dufour, PhD
VP, Technology Development
Picomole Instruments Inc.

Resonance Ltd.

March 29, 2007

Subject: Letter of support for a Canadian sub-orbital programme

To Whom It May Concern,

Resonance is a science-based company that (in addition to mass manufacturing of components of gas sensors) has developed and sold rocket, balloon and satellite payloads and to Japan and the US. Among its notable achievements are the provision of more than 25 orbital VUV calibration systems for NASA satellites including the Hubble WF/PC II, STIS and GP-B missions. It also has supplied systems for manned space flight, notably the OTCM illuminator system that was part of the Canadian component of the ISS.

All of this and more was made possible by Resonance's origins in the Canadian Rocket program which enabled the company to develop it's core VUV technology in the early 80's.

From my perspective:

1. Sub-orbital work provides an excellent educational advantage by allowing students to take on responsibility for entire projects. This is supported by my observation that many of the successful scientists in our community acknowledge the value of the sub-orbital work carried out early in their careers.

2. Sub-orbital tests afford a surprisingly economic way of reducing the risks for orbital payloads. My experience with orbital systems supports the notion that "quick an dirty" tests on sub-orbital vehicles can expose unexpected payload problems that which when corrected insure complete programme success. I think an objective analysis would show that this alone would justify significant investment in this area.

3. Sub-orbital payloads can have considerable economic benefit to Canada by fostering intensive technology development in Canadian companies. Resonance is not alone in building a successful business based on seed developments from sub-orbital programmes.

4. Sub-orbital projects stimulate technology transfer between government, industry and universities.

5. Increasingly NASA and other agencies are realizing that advances in autonomous airborne systems such as high-flying Unmanned airborne vehicles (UAVS) can enhance the science yield of satellite projects.

6. It is well recognized that important problems in the field of global warming science, atmospheric physics and other fields require sub-orbital payloads.

7. Important astronomical discoveries have been made with sub-orbital balloon flights.

8. Sub-orbital projects would help keep top young scientists in Canada by providing unique opportunities to "run their own shows".

My experience suggests that a balanced space program should a vigorous sub-orbital programme not less than 5% of the overall space budget. The economic, educational and scientific dividends to Canada would justify such an investment many times over.

Dr. W. H. Morrow

President, Resonance Ltd.

143 Ferndale Dr. N., Barrie Ontario, Canada L4N 9V9 http://www.resonance.on.ca
res@resonance.on.ca phone:. 705 733 3633 fax: 705 733 1388

Scientific Instrumentation Ltd. ph: 306-244-0881
2233 Hanselman Avenue fax: 306-665-6263
Saskatoon, SK S7L 6A7 email:s.i.l@sil.sk.ca
Canada web: www.sil.sk.ca

March 26, 2007

To whom it may concern

Re: Research using Balloons

Since 1980, Scientific Instrumentation Ltd (SIL) has provided for the design and manufacture of balloon borne instruments and payloads, since 1987 have also provided balloon launch services.

Industrial participation in the design and manufacture of payloads and instruments allows the scientist to “do the science” and provides for a very reliable platform for the data collection.

Industrial participation in providing the balloon launch service allows for the existing expertise to remain current. It will also be a benefit to industry with the provision for upgrading the equipment and technology used to support these flights.

SIL is fully supportive of suborbital scientific research and remains interested in future projects that we will be able provide engineering, manufacturing and/or provide launch services.

Yours truly,
Dale Sommerfeldt
Vice President

Thoth Technology
Make it happen

23 March 2007

Professor Kimberly Strong
Department of Physics
University of Toronto
60 St. George Street
Toronto, ON M5S 1A7

Dear Kim,

Thank you for organizing the very successful Community Workshop on Science from Suborbital Vehicles. It was a well structured conference and a fine opportunity for industrial, academic and government members of the Canadian science community to meet to discuss the use of balloons, aircraft and rockets for scientific exploration.

It is difficult to overestimate the importance of suborbital platforms in the continued growth of Canada's space-industry sector. Our company has a special interest in the use of high altitude balloons as technology-development platforms. As you are aware, these balloons provide affordable and timely access to near space, facilitating subsystem and space-instrumentation test in an environment similar to space and enabling the development and demonstration of techniques for future satellite missions. In addition to its key role in technology development, near space offers an excellent environment for atmospheric research and other remote sensing applications that are of significant interest to our firm.

As Canada's space industry continues to mature and expand, there is increased demand for highly qualified personnel. High altitude ballooning missions also contribute meaningfully to the training of qualified staff by providing students with opportunities to build, manage and operate payloads and to analyze returned data; this hands-on experience is invaluable to students' subsequent careers in industry.

I was pleased to see that Canadian industry was very well represented at the conference. The Canadian Space Agency (CSA) continually emphasizes the importance of industrial support for its programs. Enthusiastic workshop participation by ABB Bomem Inc., Bristol Aerospace Ltd., COM DEV Ltd., MPB Communications Inc., Optech Inc., Resonance Ltd., Scientific Instrumentation Ltd. and Thoth Technology Inc. testified to the recognized importance of suborbital missions to Canadian industry and should help to secure CSA funding for a Canadian suborbital program.

With best regards,

Caroline Roberts

Caroline Roberts
President & CEO

Caroline Roberts, D.Phil. (Oxon.), President & CEO, Thoth Technology Inc.
16845 Jane Street, RR1 Kettleby, Ontario L0G 1J0, Canada
tel: (905) 713-2884; email: caroline@thoth.ca
websites: www.thoth.ca, www.marsrocks.ca, www.genspect.com

Last Page of
Suborbital Workshop
Final Report