2010 Workshop on Suborbital Platforms and Nanosatellites - Report

April 14-16, 2010

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1 EXECUTIVE SUMMARY

A community-led Workshop on Suborbital Platforms and Nanosatellites was held in Saint-Hubert at the Canadian Space Agency (CSA), from April 14 to 16, 2010. The Workshop was attended by over 180 researchers, students and CSA managers with an interest in using balloons, aircraft, sounding rockets and nanosatellites as platforms for research.

The workshop had three overarching objectives which dealt with gauging the use of the different platforms, assessing the desirability of Canadian and/or international launch sites for each platform and consolidating the interest of potential leaders of a Canadian-based balloon launch facility.

This Final Report provides an overview of the Workshop, a summary of the discussions that took place, and recommendations.

The focus on these specific platforms was catalyzed by the CSA priority for building capacity in science and technology related to the space sector, and a recognition that these platforms offer access to space or near space at a cost that is accessible and on a time frame compatible with university studies cycles. In addition to offering valuable opportunities to advance science and train the next generation of scientists and engineers, these platforms also provide opportunities for researchers and research trainees to acquire diverse skills in instrument design, data analysis and project management critical to maintaining leadership in space activities.

Parallel sessions for each of the platforms allowed the participants to focus on both the research activities and the research training opportunities offered by each, as well as the infrastructure needs. The community agreed, as it had agreed in the past, that suborbital activities and nanosatellites offer valuable opportunities to advance science and train the next generation of scientists and engineers. There was convergence among the different groups on a number of broad programmatic and policy issues, but there are different needs and aspirations for the relevant infrastructure.

In summary the overarching programmatic and policy issues that emerged from the discussions are:

- The provision of, and access to, low cost platforms is a valuable and critical component of rebuilding space science and technology capacity
- CSA could fulfill a unique niche in stimulating interest in graduate work in space sciences and engineering through undergraduate research programs that foster a recognition of the utility of balloons and rockets as platforms for research
- Essential conditions for success of the capacity building thrust are:
    - a planning horizon for missions and
    - a long-range, frequent and predictable process for Announcements of Opportunity (AO)
    - a balanced program of support – recognizing the inter-dependence of mission support, research funding, personnel support (Highly Qualified Personnel (HQP) and research associates), and research infrastructure

- There is a need for greater synergy and cooperation among funding agencies, in particular CSA, Canadian Foundation for Innovation (CFI) and Natural Sciences and Engineering Research Council of Canada (NSERC), than in the past.
- CSA should play a role in enabling Canadian leadership of international missions
- CSA should ensure a balanced approach in which it supports both new and existing infrastructure that serves research needs and priorities.

Given the distinctly different situations for the various research platforms, the infrastructure requirements and issues are unique to each. Highlights of the recommendations are given below, but the full report and detailed recommendations should be reviewed to gain a full appreciation for the interdependence of these recommendations with the programmatic and policy recommendations.

1.1 AIRCRAFT

- *Parabolic flights* – the infrastructure operated out of the National Research Council (NRC) Flight Research Laboratory should continue to be supported as the primary national platform for parabolic flight research. Upgrades will be required over time. International reduced gravity platforms also provide scope for research and training.
- *Earth observation* – in addition to continued use of government aircraft platforms, there should be consideration of low cost aircraft where sophisticated platforms are not required.

1.2 BALLOONS

- *Small payloads (<70 kg)* - Canadian suppliers can meet the projected needs for these flights over the next decade.
- *Medium payloads (> 70 kg and < 1 tonne)* – There is value in establishing a mobile Canadian launch facility for medium sized payloads.
- *Large payloads large (>1 tonne)* - An agreement between CSA and an international provider (such as NASA-CSBF, CNES, Sweden) to launch Canadian payloads should be pursued in coordination with the flight needs and funding opportunities for these payloads.

1.3 SOUNDING ROCKETS

- *Short and longer term* - a flexible, open and timely mechanism to allow Canadian scientists to respond to international flights of opportunity
- *Longer term* - Follow through on development of lower cost rocket platforms (e,g., Excalibur) and CRV-7 launcher capability

1.4 NANOSATELLITES

- Recognize, support and better exploit existing Canadian nanosat infrastructure and expertise at UTIAS/SFL
- Direct new infrastructure funding to complementary facilities

These recommendations and conclusions emerging from the Workshop reflect the fact that suborbital platforms are a necessary underpinning of a strong Canadian Space Program in the context of a predictable and regular support for missions and the related research costs. The research community looks forward to the response of the CSA to this Report and its recommendations.

2 INTRODUCTION

April 14-16 marked the 2010 Suborbital Platforms and Nanosatellites Workshop sponsored by CSA. The planning committee brought together over 180 participants, mainly from Canada, but also from Europe and the United States (U.S.), comprised of researchers prominent in the many scientific disciplines such as, but not limited to, atmospheric science, astronomy, space physics, microgravity and representatives from the funding agencies, industry and government departments.

Suborbital activities, which for the purpose of this workshop included the use of aircraft, balloons, sounding rockets, and nanosatellites offer valuable opportunities to advance science and train the next generation of scientists and engineers. They also provide opportunities for researchers and research trainees to acquire diverse skills in instrument design, data analysis and project management critical to maintaining leadership in space activities. Suborbital platforms and nanosatellites offer access to space or near space at a cost that is accessible and provide a schedule that is compatible with university studies cycles. Building capacity in the science and technology space sector is a priority of CSA, in particular through promoting the use of accessible and cost effective suborbital platforms and nanosatellites.

The purpose of the 2010 workshop was to consult widely with interested users, whether from academia, industry or government, anticipating the delineation of important areas of research and infrastructure needs regarding the usage of suborbital platforms and nanosatellites.

3 WORKSHOP CONTEXT

A number of key events lead to this 2010 Workshop. In 2004, a CSA-led Nanosatellite Workshop assembled interested participants. Major outcomes of the workshop were documented and can be found in the Nanosatellite section of the Backgrounder (Appendix C). In 2007, the user community for suborbital platforms assembled and discussed the needs to access space. It assembled over 80 participants, who had an interest in using balloons, aircraft, and sounding rockets as platforms for scientific exploration. Some of the goals of that earlier 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, and
- to determine the level of interest in these flight opportunities in Canada.

The Final Report, called Community Workshop on Science from Suborbital Vehicles (Balloons, Aircraft, Sounding Rockets), included a Vision for the Sub-orbital Program:

> "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 [*aircraft, high-altitude balloons, sounding rockets*]. 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."[1]

3.1 CSA CONTEXT - 2010

CSA recognizes that researchers need access to space at frequent intervals to hone their skills, generate research results at a fast pace and train highly qualified people in a reasonable period of time. It has identified rapid and cost-effective access to space, via nanosatellites, and sub-orbital platforms as a priority for future CSA programs and as a central element of its capacity building priority. To this end, it is seeking to enhance its programming to facilitate access to sounding rockets, balloons, aircraft and nanosatellites as research platforms and for technology development, validation and demonstration.

As a follow up to the 2007 Workshop recommendations, as well as the 2004 Nanosatellite Workshop, CSA is implementing a new grants and contributions program to support regular campaigns. The new CSA program intends to provide funding for, amongst other things:

- Instrumentation development and testing/validation related to flight opportunities in Canada and abroad undertaken by Canadian universities and industry – recognizing the value for graduate training.
- The costs associated with research campaigns that are carried out through Canadian or international collaborations.

[1] Community Workshop on Science from Suborbital Vehicles (Balloons, Aircraft, Sounding Rockets), Final Report, 2007, p. 28

In addition, and subject to the outcomes of the discussions of the 2010 Workshop, CSA intends to provide funding, in partnership with other sources, for the development and maintenance of a Canadian-based balloon launch facility. The funding level for these activities has yet to be finalized.

3.1.1 Daily Overview

In this context, CSA hosted the community led workshop at the John H. Chapman Space Centre in St-Hubert, Quebec on April 14-16, 2010. All participants had received a backgrounder document prior to the Workshop to help prepare them for the discussions to take place at the workshop (Backgrounder in Appendix C).

The first day of the Workshop began at 13:00 where CSA presented its re-organization and view of the future. The latter part of the afternoon was devoted to presentations made by leaders in the community who gave a presentation on the up-to-date status of the different platforms in Canada.

The second day was devoted to parallel sessions focusing on each of the platforms at which there were presentations on science, existing infrastructure and forecast needs by different users (List of presentations and presenters in Appendix A). Each parallel session also addressed the specific objectives that had been sent prior to the workshop (see section 3.2).

The third day consisted of a plenary session, where the chair of each parallel session presented a summary of the findings from the previous day. The president of CSA also attended the last part of the workshop to gain first hand information. The workshop finished at 13:00.

3.2 THE OBJECTIVES OF THE WORKSHOP

The overarching objectives of the Workshop were:

- To assess and document community usage (nature of science, likely payload requirements and frequency) of suborbital platforms (aircraft, balloons and sounding rockets) and nanosatellites as research and training tools over the next 5-10 years.
- To assess the desirability of Canadian and/or international launch sites for each platform.
- To consolidate the interest of, and initiate discussions with, potential leaders of a Canadian-based balloon launch facility.

The specific questions put to each of the parallel sessions were:

1. What research areas are enabled by these platforms (over and above issues addressed in the 2007 Sub-orbital and 2004 Nanosatellite Workshops and that are reproduced below)?
2. How can the proposed activities utilizing these platforms best contribute to training the next generation of the space workforce in Canada?
3. What infrastructure exists in Canada and/or internationally that enables access to these platforms?
4. What infrastructure upgrading, building or replacing is needed in Canada to enable optimal access to these platforms?
5. What investments by the Government of Canada (GC) would you recommend to meet CSA’s goals? (Infrastructure and/or research investments)
6. Who are the main points of contact /champions in the community who could or would lead the effort to further develop a program in this area?

3.3 ATTENDANCE

The workshop was well attended with over 180 participants, over the three-day workshop. Participants indicated the platform that most interested them when they registered on the web site. The division of interest was as follows:

- 42.5% Nanosats
- 21.6% Balloons
- 20.4% Aircraft
- 15.5% Sounding Rockets

Appendix D provides additional information on the participation in the workshop.

4 REPORT FROM THE AIRCRAFT SESSION

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4.1 INTRODUCTION

Aircraft have played an essential role as suborbital platforms for many decades and are used for pursuit of a diversity of research topics. Different types of aircraft can be used to conduct research, multiplying the number of opportunities to carry out science or technology investigations. In this workshop, aircraft usage focused on two main themes: Microgravity research, using parabolic flights and Earth Observation research (includes research on the atmosphere and research on the interactions between Earth surface and lower atmosphere – the boundary layer) using numerous aircraft. In this section, considerations on Microgravity research will be dealt with first, followed by Earth Observation research.

The reduced gravity environment onboard parabolic flight aircraft eliminates gravity-induced effects, such as buoyancy, thermal convection, and mixing due to different densities, permitting phenomena to be observed without said gravity effects. This unique research environment provides data that cannot be obtained in most Earth laboratories. From these, physical effects that may otherwise be obscured by the effect of gravity are observable and can be included to verify different models. The ability for rapid turn-around between experimental trials and "hands-on" operation of apparatus by the investigator makes this platform unique among other reduced-gravity techniques (e.g., sounding rockets, orbital platforms).

The use of research aircraft to observe both the atmosphere and properties of the earth's surface also delivers some unique capabilities to the suborbital program. These include the ability to target observations very precisely, a variety of sophisticated and comprehensive payloads, the ability to make continuous measurements in three dimensions and over time, and a well established risk management strategy for operations. In Canada, there are state-of-the art aircraft with world class research capabilities in some areas of earth observation. There have been noteworthy successes in space applications both using Canadian aircraft and through international partnerships using foreign aircraft. Challenges in this field are a consequence of the multi-disciplinary nature of the earth observation applications and the wide variety of requirements for various aircraft platforms. From the university perspective, the main difficulties have been

a. limited access to aircraft facilities for undertaking experiments, and
b. limited funding for airborne measurement programs, in the atmospheric and climate sciences.

This Aircraft session of the workshop was well attended with university researchers from across the country and from abroad as well as from the Government of Canada (GC), gathered to discuss the future use of aircraft for Earth Observation and Microgravity research.

4.2 RESEARCH

4.2.1 Parabolic Flights

Scientific, technical, and operational research that is performed in Canada using parabolic flight aircraft includes:

- **Material science**: electromagnetic levitation, rapid solidification of undercooled melts, thin film growth of non-linear optical materials, semiconductor nanowire growth, fractal aggregation and mixing of dust particles
- **Fluid Physics:** contact angle and contact line studies, superhydrophobic surface studies, and phase separation processes: bubble-bubble interaction, liquid-bubble interaction, and solid-liquid interaction
- **Combustion science**: laminar dust combustion, heterogeneous combustion, diffusion, kinetics)
- **Life sciences and biological research:** human vestibular experiments, physiology in general
- **Development and Qualification**: mission concept and feasibility designs, validation, sub-system and integration of technology, operational procedure development and validation.

In addition, parabolic flight aircraft are used to develop and qualify experimental designs and evaluate concepts and procedures for longer-duration experiments.

In recent years, Life Sciences and Biological Research have not been extensive users of parabolic flight aircraft, due in part to a shift in research in this discipline to on-orbit platforms and the International Space Station (ISS) in particular. The Workshop was also light on participants from these communities. This report will thus focus primarily upon Physical Sciences research.

4.2.2 Earth Observation

Topics that have been addressed with research aircraft include atmospheric composition, carbon cycle, climate variability and change, earth's surface, water and energy cycle, and weather. Specific applications include instrument development and testing, calibration/validation activities for satellite and surface-based remote sensing instruments, and process scale studies for algorithm development and feasibility studies.

A series of presentations at the breakout session highlighted some of the work using research aircraft that has been done or is ongoing by Canadian scientists. For atmospheric applications, these included: arctic cloud chemistry (Hg, O_3, BrO), surface exchange processes (boundary layer ozone), impact of Boreal forest fires, spatial variability of CO_2, aerosol indirect radiative forcing, mixed phase clouds, water vapour in the Upper Troposphere – Lower Stratosphere (UTLS), arctic cloud properties, and precipitation features of Arctic storms.

There was concern expressed at the workshop that there was little participation by those who look at surface phenomena (marine, terrestrial, cryosphere). Nevertheless, some examples were presented of the use of aircraft, either with synthetic aperture radar or microwave radiometers, to study the properties of sea ice, the snow water equivalent of snowpack, and soil moisture. The workshop permitted the participants to underline that topics dealing with surface properties are equally important to those dealing with the atmosphere.

4.3 PEOPLE

4.3.1 Parabolic Flights

The personnel involved in parabolic flight-based research are drawn primarily from academia. Parabolic flight experiments provide outstanding opportunity for students and Post-Doctoral Fellows (PDF), within the span of their thesis program, to see an experiment from inception, design and construction, ground-based and parabolic flight testing, data collection and analysis, presentation and publication. This feature represents an enormous contribution to HQP development and training in general, and is deemed essential to implement Canada’s full scientific utilization of our rights onboard the ISS over the next decade.

The potential to extend this experience to undergraduate students would be particularly desirable from a recruitment perspective, similar to the European Space Agency’s (ESA) “Fly your Thesis” or student parabolic flight campaigns. Some Canadian pilot projects of this type have been started in the past, but require sustained funding to have an impact on the Canadian community.

While CSA underpins the microgravity research conducted in the country, the main users are found in universities across Canada. Appendix B gives an idea of the universities that are the most active in the domain. A few researchers in the private sector have made use of the parabolic flights to test some concepts related to emergent technologies.

4.3.2 Earth Observation

The workshop provided the opportunity to identify expertise in the use of research aircraft by the university community both for innovative space science applications and in the training of HQP. It was found that scientists in academia as well as in government think that the aircraft is a useful tool to train students, both undergraduates and graduates. Aircraft offer opportunities to perform science experiments that are unparalleled by the more sophisticated/traditional space platforms because the time constraints are easier to adjust to the students’ study cycle.

4.4 INFRASTRUCTURE

4.4.1 Parabolic Flights

The main platform used by Canadian researchers is the Falcon-20, operated by the National Research Council of Canada (NRC), Flight Research Laboratory (FRL). This aircraft has recently undergone modifications to permit it to perform as many as 40 parabolas in a single sortie. This capability is now being exploited by a few Canadian researchers for increased access to the reduced gravity environment.

The aircraft is in good condition and, if properly maintained, can continue to be operated for several more years. For its eventual replacement, examination of using a Canadian-built aircraft should be explored, considering the positive public relations aspects of flying a Canadian aircraft (the current Falcon-20 was built by Dassault Aviation in France).

While the NRC Falcon-20 is anticipated to being sufficient for anticipated demand and requirements for parabolic flight research in Canada for the coming decade, the existing payload assembly room at the NRC, FRL (Ottawa) should be upgraded with a ground-based electronics lab to permit aircraft users to take better advantage of their window of available flight time. Modification of the Falcon-20 interior with the addition of a “Plug and Play” hardware rack would facilitate the vision of undergraduate and graduate-student initiated experiments.

Other experimental modules that could be added to the Falcon-20 include, for example, a high temperature surface tension and groove apparatus (three-phase surface tension) for material science. Post-flight sample analysis capabilities that occur off-site e.g. Scanning Electron Microscope (SEM), Transmission Electron Microscope (TEM), X-ray, Atomic Force Microscope (AFM), lab-scale microtomography, and atom probe); are urgently needed. CSA can assist researchers by contributing to the CFI applications requesting these types of infrastructure for analysis of post-mission samples analysis, and in addition, CSA can be a leader in Canada to assist researchers’ access to unique international facilities (e.g., synchrotrons) for post-mission sample analysis

The Falcon-20 aircraft is complementary to other parabolic aircraft (Airbus A300B) and interesting stepping stone to development of experiments for orbital platforms. The Airbus A300B (operated out of Bordeaux, France by Novespace, a subsidiary of Centre national d'études spatiales (CNES)) has extensive on-board and ground-based facilities that are utilized by a few Canadian researchers. Airbus A300B flights based out of Canada (the NRC FRL in Ottawa in particular) would be possible if a sufficient domestic demand for parabolic flights existed and would permit multiple Canadian experiments to fly simultaneously.

4.4.2 Earth Observation

The capabilities within Canada are:

- The NRC, FRL, operates 9 experimental aircraft and supports the associated infrastructure for incorporating guest or short term systems into these aircraft. Among the currently equipped NRC aircraft are a Twin Otter, Convair-580, a T33 each of which has been equipped for atmospheric or earth observation research;
- NRC has specialized equipment for earth observation that includes a hyperspectral Short Wave Infra Red (SWIR) imager and a dual channel, dual polarized Doppler radar NRC Airborne W and X-band polarimetric Doppler radar system (NAWX);
- Environment Canada (EC) operates a Convair-580 with onboard C-band and X-band Synthetic Aperture Radar (SAR) systems;
- Atmospheric Science and Technology Directorate (EC) has a suite of instrumentation for use on aircraft that includes in-situ probes (aerosol to precipitation), remote sensing (radar & Light Detection and Ranging (LIDAR)), and trace gas measurements;
- Canadian commercial operators also provide aircraft for research purposes.

In addition to exploitation of Canadian facilities, several examples were given at the workshop of foreign aircraft used by Canadian scientists. One was the Polar 5: DC-3 / Basler 67 aircraft of Albert Wegener Institute of Germany that operated in the Canadian Arctic on the Pan-Arctic measurements for Arctic Climate Model Validation in 2009. A second example was the flight testing of the LIDAR for the Phoenix Mars Mission on the Australian Egrett aircraft.

These illustrate the types of collaboration with the international community that frequently occur when developing programs that utilize research aircraft. Other foreign aircraft renowned for space applications of their airborne research programs are the National Aeronautics and Space Administration (NASA) ER2 High Altitude aircraft, the United Kingdom (UK) Facility for Airborne Atmospheric Measurements (FAAM) Bae-146 aircraft, and the NASA Global Hawk Unmanned Aerial Vehicle (UAV).

Overall the community is well served by this mix of Canadian infrastructures and access to foreign platforms. However, according to the community, there is potential for more use of smaller aircraft owned either by NRC or a commercial operator that would fill a niche in this field that has not been properly realized to date.

4.5 FUNDING

4.5.1 Parabolic Flights

The main issue that researchers in the reduced gravity research community have faced in the last decade is continuity of funding from ground based research, to flight opportunities, to analysis of flight samples. Interruptions in regular AO have resulted in practical experience and "know how" being lost. Regular and long term funding decreases the risk to Principal Investigators (PI), who may otherwise be forced to fund graduate students for the remainder of their thesis programs from their own operating grants. The duration of programs funded under any new G & C program should remain compatible with the period required for a typical PhD program (i.e., 4-5 years).

The introduction of Research Chairs at universities would be a significant contribution to capability development and maintenance. Given the aging of the current generation of reduced gravity researchers and the need to maintain this research sector in Canada by attracting a new generation of PIs, Research Chairs are the best mechanism to affect this renewal. Since reduced gravity research is not a research topic per se, but rather a tool used in various established research disciplines, Workshop participants recommended that a Research Chair should be created in each of the space physical science research areas: material sciences, fluid physics, combustion science, protein crystal growth, and fundamental physics.

Increased funding per project (as opposed to more funded projects) would permit more scientific investigations to take advantage of aircraft platforms available in Canada. A modest increase per project supporting the addition of one or two graduate students would allow greater specialization in each students research area, enabling more frequent parabolic flight campaigns (increased data generation) and fostering focused modeling and analysis (increased data utilization).

Finally, a commitment to identifying, selecting, and developing experimental investigations that have a strong scientific rationale for evolution to longer duration (suborbital, short-duration on-orbit, and ISS) reduced gravity platforms is essential. This is crucial if Canada is to capitalize on two decades of ground-based reduced gravity research and to take full advantage of Canada's allocation of ISS time and resources.

4.5.2 Earth Observation

The workshop provided examples of suborbital projects with an aircraft component funded directly by CSA, by the Canadian Foundation for Climate and Atmospheric Science (CFCAS), by equipment grants from the Canadian Foundation of Innovation and by partnering with external collaborators outside of Canada.

A suborbital Grants & Contributions (G&C) program would enhance an Earth Observation Studies program using aircraft by allowing university investigators to propose projects of interest to CSA within and outside Canada. This would include the integration of university equipment onto an aircraft for use in targeted measurement campaigns. The aircraft could be government-owned or commercially available, Canadian based or from other countries. The ability to leverage and strengthen existing infrastructure through the new G&C program would benefit Canadian researchers.

Financial support of such initiatives could include travel and salary support for university HQP participating in these aircraft measurement campaigns, logistics costs, technical support and expenses associated with ground-based observations that support the aircraft observations.

Another component of the program could be funding support for the analysis and interpretation of observations from past and ongoing aircraft campaigns that did not involve university measurements directly.

A final component discussed during the workshop was that funding could be available to have students spend time working in government laboratories such as NRC, EC and Canada Centre for Remote Sensing (CCRS).

4.6 RECOMMENDATIONS

The list of all recommendations is available in Appendix E.1 Aircraft Session.

4.6.1 Parabolic Flights Research

1) CSA should structure and schedule all future AO to ensure stability of funding, guaranteeing continuity of graduate student and post-doc support, for research programs that continue to meet objectives and win approval in a peer-review process.
2) The funding level per project should be increased sufficiently (even at the expense of funding fewer projects) to enable adequate personnel for graduate student and post-doc specialization (hardware development, data analysis, modeling, etc.), permitting a greater scientific return on program investment.
3) Funding should be integrated into identifying and developing scientific investigations that have evolved to required longer-duration platforms (the ISS, in particular). Commitment is required to develop the hardware necessary to transfer investigations originating from parabolic flight research to other platforms (sounding rocket, ISS, etc.).

4) The Falcon-20 operating out of the NRC Flight Research Laboratory should continue to be supported as the primary national platform for parabolic flight research. While the capacity of the recently upgraded aircraft is sufficient for current and anticipated research needs, further investment into ground-based facilities for better on-site payload integration and access to off-site facilities for post-flight analysis of samples would increase the results generated by flight campaigns.
5) Over the next decade, the eventual replacement of the Falcon-20 with a pre-existing, Canadian-built platform should be explored. The use of a Canadian-built aircraft would present a substantial public relations opportunity.
6) The Canadian reduced-gravity research program should continue to build upon collaboration with other international programs via utilization of their reduced gravity platforms and the ESA Airbus A300B in particular. The Canadian Falcon-20 and the European Airbus A300B are seen as filling highly complementary roles.
7) The G&C program and Research Chairs should be used to promote renewal for a new generation of academic researchers that utilize reduced gravity for physical science research. The current generation of researchers in this field is maturing, and the Research Chairs program could be a means of attracting talent of international standing to Canada.

4.6.2 Earth Observation Research Aircraft

1) CSA should structure AOs that:
    a. Call for multi-disciplinary aircraft studies in support of major missions of interest to CSA.
    b. Provide funding for aircraft flight hours, and integration and access costs for existing or new equipment and for the training of HQP
2) CSA should coordinate its G&C program with other university funding agencies to improve university access to earth observation funding through:
    a. Presenting the case for an extension of the NSERC Ship Time Program to aircraft work
    b. The provision of CSA funds to enhance CFI grants
3) There should be promotion of the use of low cost aircraft to facilitate entry level or more simple projects by this community, where requirements do not dictate sophistication of NRC aircraft.
4) CSA should enhance its support for NRC, CCRS and EC facility usage to maintain necessary engineering readiness to better serve the university community. A Memorandum of Agreement (MOA) with a discretionary framework between CSA and Other Government Departments (OGD) to support this type of activity should be pursued. An example of this approach is the existing Memorandum of Understanding (MOU) between EC and NRC for collaboration on aircraft programs, and the NRC-CSA MOU for parabolic flight.

CSA should commission a white paper from the earth observation community that further documents existing aircraft capabilities within relevant government agencies (NRC, EC, CCRS), university interest in earth observation studies using aircraft and future directions of research using aircraft capabilities for earth observation within Canada.

5 REPORT FROM THE BALLOON SESSION

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5.1 INTRODUCTION

The goals of the balloon breakout session were to determine the science-driven launch and infrastructure needs for the Canadian balloon community in the research areas of Astrophysics, Atmospheric Science, Space Physics and Engineering, and to explore different options for providing reliable access to balloon launches for the Canadian community, including existing national and international opportunities and interest in university-based balloon facility.

During the 2007 Workshop, there was an extensive discussion of the key science questions of interest to Canadian scientists that could be addressed using balloon experiments. These questions covered a wide range of topics in Atmospheric Science and Astrophysics. The balloon session was designed to build on, rather than repeat, this previous discussion because these research questions are still of strong interest to the community. In the ballooning breakout session, the morning was devoted to talks and discussion on current and future balloon projects with Canadian involvement, and the afternoon was devoted to talks and discussion on various launch and infrastructure opportunities designed to respond to the objective of building capacity.

This summary is broken into sections on Research, People, Infrastructure and Recommendations. The topic of funding was a continuous thread throughout the balloon session so it will be discussed as required in each section.

5.2 RESEARCH

Scientific ballooning provides inexpensive access to near-space, enabling the training and development of HQP while engaged in compelling science that can transform fields of research. While inconsistent funding levels have been a challenge, significant expertise exists within the Canadian community, which can boast of important scientific advances. There is potential for future growth if sufficient stable funding can be secured.

5.2.1 Astrophysics

The past decade saw important Canadian contribution to two of the most important recent balloon projects: *BOOMERANG (Balloon Observations Of Millimetric Extragalactic Radiation And Geophysics)*, which measured the age, geometry, and content of the Universe, and *BLAST (Balloon-borne Large-Aperture Sub-millimeter Telescope)*, which observed the sky at the 15K thermal peak of interstellar dust, identifying the source of 50% of the Universe’s starlight previously hidden in dust, and constraining processes of star formation.

Speakers in the morning session presented overviews of Canadian contributions to upcoming and proposed missions (see Appendix A, Balloon Session). Science goals include understanding star formation, galaxy evolution, inflation and the Big Bang, cosmic rays, and constraining dark energy. Due to a lack of sufficient stable funding, none of the current projects are Canadian led, though within Canada there is both the expertise and interest to lead a major mission, as a precursor to an astrophysics satellite.

The typical astrophysics balloon experiment involves several universities, costs a few million dollars (less than 10), and takes half a decade from funding to flight. In order to fly the largest possible telescope collecting area, for as long and high as possible, the experiments push the limits of the launch envelope in terms of payload mass, size, and flight duration. The gondola and pointing system for these experiments are typically specialized, and are integrated into the development of the experiment. For astrophysics flights, the payload should be flown at high altitude (~35 km) and from a polar location (such as Antarctica) where long flight duration can be achieved. Statistics for the typical astrophysics balloon payload are listed in Table 5-1.

5.2.2 Atmospheric Science

Canada has a long tradition of expertise in stratospheric ballooning for atmospheric science, with notable successes which include the Stratoprobe series of balloon flights in the 1970s and 1980s and the four Middle Atmosphere Nitrogen TRend Assessment (MANTRA) flights between 1998 and 2004. Both of these programs investigated the composition of the stratosphere using a suite of instruments that determined the vertical concentration profiles of trace gases including O_3, NO_2 and HNO_3. Stratoprobe was led by the Atmospheric Environment Service of Canada and MANTRA was a university-led program supported through CSA's First and Second Small Payload Programs. However, the end of the Small Payloads program has greatly reduced activity within Canada.

Despite this setback, the community remains enthusiastic about ballooning. The morning session had a full program of talks on current and future balloon missions (see Appendix A) with goals which included studies of greenhouse gases and aerosols, investigations of atmospheric chemistry, composition and dynamics, validation and calibration of satellite-borne instruments, and development of new instrumentation for future balloon and satellite missions.

Typically, atmospheric instruments weigh less than 50-60 kg, are developed and operated by one research group, and have a turn-around time of a couple of years from funding to flight. The flight platform usually requires azimuthal pointing to orient instruments toward or away from the sun and fine-pointing control mechanisms are incorporated into each instrument, as required. Both stand-alone flights of a single instrument on a small platform, and grouped flights of several instruments on a single gondola are common. Desired launch locations depend on the specific science goals of the experiment and can range from low- and mid-latitudes to polar latitudes. Flight altitudes range from near the surface using tethered balloons for boundary layer studies to upper stratosphere (>35 km) for limb and nadir viewing studies. The length of the flight can range from a few hours (example, sunrise or sunset measurement) to much longer with a typical flight being one day long. Statistics for the typical atmospheric science balloon payload are listed in Table 5-1.

5.2.3 Space Physics and Engineering

During the morning session, the applicability of scientific ballooning to Engineering and Space Physics was also discussed. The balloon environment provides a unique platform for the development of control systems, connected to, or independent of an ongoing mission. These engineering experiments do not have specific altitude, flight duration and launch location requirements and can be flown as part of a larger mission (hence the “passenger” designation in Table 5-1). There was definite interest in working together to provide space (as available) for engineering experiments.

Additionally, high altitude balloons reaching approximately 35 km provide an ideal platform space physics studies of the coupling of the magnetosphere-ionosphere-atmosphere. Balloon measurements of electric and magnetic fields can provide data that complements those data from satellite and ground-based sensors. A topic of particular interest is the study of the loss of relativistic particles from the Van Allen belts, since these particles are implicated in space weather damage and even total loss of satellites. Satellites currently cannot measure key loss processes so balloon measurements can provide a critical measurements in this area. Typically space physics instruments are small 10-20 kg payloads that could fly on their own or as a passenger on a larger payload.

Statistics for the typical engineering and space physics balloon payload are listed in Table 5-1.

TABLE 5-1 – TYPICAL PAYLOAD NEEDS FOR DIFFERENT RESEARCH DISCIPLINES

	Astrophysics	**Atmospheric Physics**	**Space Physics**	**Engineering**
Payload Mass	2000 – 3000 kg	1 to 1000 kg (50 kg typical)	10 kg	10 kg
Flight Altitude	35 km	>30 km free fliers <3 km tethered	>35 km	Passenger
Flight Duration	1 to 100 days (14 days typical)	2 hours to 1 month (1 day typical)	1 month	Passenger
Launch Location	Polar	Varied	Polar	Passenger

5.3 PEOPLE

A fundamental goal of a balloon program is the training of HQP, through hands-on involvement in cutting-edge science and innovative instrument development. This came up often in the discussions and presentations. Ballooning provides an excellent opportunity for students to become involved in all aspects of a project from development and construction of an instrument through flight and post-flight data analysis. It provides access to near-space on a faster time scale than is possible for a satellite mission. The life cycle of a balloon mission is better matched to the length of a PhD so a student can participate in and contribute to all areas of the project.

The educational impact of past ballooning missions is profound. In the past decade, approximately thirty graduate students at Canadian universities – working on topics ranging from mechanical engineering to theoretical physics – have worked on astrophysical balloon projects. Many of these students are now involved in the Herschel and Planck satellites, both ESA missions. The results from the four MANTRA balloon campaigns were involved in more than 15 graduate theses and five undergraduate research projects in atmospheric physics and chemistry. Many current and proposed atmospheric science satellite missions are led by people with ballooning experience. An active balloon program builds both capacity and demand for satellite projects.

The opportunities for training HQP in how to engineer a system for a space-like environment occur in scientific instrument development and in payload flight systems development, including the gondola, pointing systems and communications. In both the atmospheric science and astrophysics disciplines, development across the entire spectrum from science instrument to flight systems has shown considerable training value. The morning presentations of the four funded upcoming astrophysics experiments were all made by trainees (three graduate students and one Post Doctoral Fellow), who all stressed the tremendous value they find in the end-to-end development of instruments or missions, flight, and data analysis experience of their projects. Half of the atmospheric science presentations were given by scientists who got their start in atmospheric ballooning.

As a supplement to the HQP training in science driven projects, the potential of a program for short-term undergraduate projects was discussed. The goal of this program would be to interest students in ballooning and experimental science early in their university careers. Similar programs exist in the U.S. and Europe (e.g., the European Balloon-borne Experiments for University Students (BEXUS) program), in which undergraduate students propose to build and fly (< 35 km) small light-weight (40-100 kg) payloads on a standard gondola. The intent is for these projects to be fully student led, with the whole program, from proposal through flight and final write-up, occurring within an 18-month time span. As Canada is a member of ESA, Canadian students could participate in the BEXUS program subject to confirmation of support for their proposal from the CSA. To develop a Canadian program of this type, we would start with the opportunity for one student-led flight project per year in order to provide a similar level of access as European and U.S. students have. The discussion explored different methods of providing this access, including dedicated small payload (single instrument) launches, association with larger science payloads, or through foreign programs. It was felt that providing access to a program like this to Canadian students would be of benefit at modest cost. It was felt that any of these options could have merit and should be explored further.

Launch and balloon operations also do have some potential for training HQP – mainly in training future balloon operators – but this is less significant in its applicability to space. For this reason, it was concluded that to maximize the training potential, the highest priority is to develop and maintain a vibrant university-based balloon science program, with the development of launch capability built to support the needs coming out of a revitalized program.

In addition to investing in research and infrastructure, there is a need for investment in community building for Canadian balloon researchers. This Workshop showed the importance of communication within the community. Funding opportunities for community building should be provided for activities such as meetings to share expertise. These meetings will also be useful to raise the profile of opportunities for balloon experiments and to reach out to a wider group of researchers.

5.4 INFRASTRUCTURE

From the discussion of current and future balloon projects, a projection was made of the launch needs for the community over the next decade. This discussion assumed the existence of an actively funded program and only modest growth of faculty staffing levels. The discussion of how to meet these launch needs included both domestic and foreign options, with presentations made by two Canadian providers (Scientific Instruments Limited (SIL) and Continuum Aerospace) and by representatives of four potential foreign partners (Columbia Scientific Balloon Facility (CSBF), CNES, Swedish Space Corporation (SSC) and Agenzia Spaziale Italiana (ASI)). Table 5-2 summarizes the discussion on projected launch needs in Canada over the next 10 years along with the status of Canadian and foreign launch infrastructure.

TABLE 5-2 – CANADIAN AND FOREIGN LAUNCH CAPABILITIES AND INFRASTRUCTURE

Class	Large (>1 Tonne)	Medium	Small (<70 kg)
Launch Type	Truck launched	Truck launched	Hand Launched
Projected Launch Demand over the Next Decade	3 CSA funded launches + 10 foreign partner funded launches	5 – 8 Canadian payloads + additional foreign demand	40 – 100 Canadian payloads
Canadian Launch Infrastructure	No significant infrastructure	Some equipment & expertise at SIL No facility	Canadian corporation have or are developing this capacity
International Infrastructure	Sufficient foreign capacity exists; eager to help us	Sufficient foreign capacity exists; eager to help us	

Three of the foreign launch providers represented at the meeting (France, Italy, and the U.S) have the capacity for launching large balloons (> 1 tonne payload) needed by astrophysics experiments. The U.S. program operating from NASA's CSBF provides the type of long duration flights from polar sites needed by the currently funded projects. Also the CSBF is pursing the development of 1 Tonne or heavier ultra-long duration mid-latitude flights with super-pressure balloons that would facilitate future optical or near ultra-violet (UV) experiments.

For experiments in this large balloon class it was the consensus of the discussion that a Canadian launch option would be prohibitively expensive given the projected demand and current lack of infrastructure and experience within Canada. CSBF expressed interest in providing these launches to Canadian-led projects. An agreement between CSA and a foreign provider such as

NASA/CSBF would be able to meet the demand for this class of experiment over the next decade.

The atmospheric community projected its largest demand over the next decade to be for small balloons, with payloads of less than 70 kg flown to altitudes over 30 km. This balloon class has the advantage of being launchable from almost any location, in a much wider weather range and shorter turn-around time than the larger (> 70 kg) balloons, with a payload capacity sufficient for a wide range of single instruments. Two Canadian vendors, SIL and Continuum Aerospace, both expressed interest in providing the Canadian community with launches in this light-weight class. SIL has had experience in this weight class of over 200 launches with no scientific data loss due to ballooning failures. Both vendors expressed interest in providing a turnkey solution, including telemetry and possibly coarse pointing control. It is anticipated that one or more Canadian vendors could meet the demand for this small balloon class over the next decade. In conjunction with the discussion of turnkey solutions, there was also interest from the community in development of generic flight systems including pointing control for science instruments. This development should be explored with active community engagement to ensure that these systems will meet the needs of current or future projects.

For simultaneous atmospheric measurements by multiple instruments, a common gondola carrying the suite of instruments is required. In this medium class of payloads, the mass of these combined instrument flights can reach several hundred kilograms, and requires more elaborate launch procedures, involving a truck launch or tow balloon. The demand for launches by the existing community, if well funded, was estimated at 5 – 8 per decade. Between 1987 and 2004, SIL launched 22 balloons in this medium class, with 4 post-launch failures that impacted the science return. University of Saskatchewan expressed strong interest in re-establishing a balloon launch facility in Canada.

5.4.1 A Canadian Launch Facility

While there was broad consensus that a Canadian solution should be sought for the launching of small balloons, considerable time was spent in discussion of a Canadian balloon launch facility primarily for medium-sized balloons. The University of Saskatchewan is eager to lead the effort in building a launch facility, and is willing to invest to make it a reality. They stressed that Saskatchewan is an excellent location to launch and recover balloons, given the favourable weather, low population density, and good transportation infrastructure to allow for relatively easy recovery of payloads. For this medium class of payloads, the consensus in the discussion was that it would be desirable for many of the launches projected over the next decade to be from locations at different latitudes including mid-latitudes such as Saskatchewan. For this reason, the discussion focused on a mobile launch capability to meet these needs, rather than tying all launches to a specific launch location. It is however necessary to have a fixed infrastructure to support the mobile facility and house laboratories, equipment and personnel. It was also brought up that there are other necessary tasks related to the launch and recovery of balloons within Canada, including flight permissions and recovery logistics. The planning of a balloon facility must take these into consideration. There is also a possibility of foreign launches being done in Canada and the foreign launchers desire assistance of this type.

The concern that the Canadian facility could be built without sufficient demand to make it a useful endeavour was discussed. Demand is highly dependent on the interests and size of the community, and on the level of reliable funding. It was considered likely by some that sustained adequate funding will generate sufficient demand for a Canadian launch facility of the proposed capacity to be a good investment. For this reason, it was the consensus of the discussion that the funding of scientific programs should take precedence over infrastructure development and that the funding of the launch capability must be based on its own program, rather than being tied to funding decisions of individual scientific projects.

Additionally, some felt that the construction of a Canadian launch capability should not be rushed into, but should follow from demonstrated demands of future funded projects. In this respect, it will require time to develop a Canadian balloon facility. By making a research investment in a vibrant and sufficient program to fund scientific ballooning projects, the demand for launches will grow and thus will allow full utilization of a Canadian facility as it comes on line.

Through the presentations and discussion, there was interest expressed by some of the foreign partners in collaborating with Canada. This interest is in two areas: in providing launches for Canadian payloads and in launching foreign payloads from Canadian territory (or alternately landing them in Canada after launching from northern Europe). This type of collaboration is advantageous for Canada in two ways. In the near term, it can be a way to meet launch needs while the Canadian balloon facility is being developed. In the longer term, once the Canadian facility is operational, having foreign users will enhance the long-term sustainability of the facility. While it is not possible to launch medium sized balloons over many mid-latitude sites in Europe because of the high population densities, it is still possible to do this in Canada. This makes Canada an attractive place for foreign partners, such as CNES. It is recommended that CSA actively pursue international partners/users for a Canadian balloon facility.

5.5 RECOMMENDATIONS

The list of all recommendations is available in Appendix E.2 Balloon Session.

The discussions led to the following recommendations:

1) The highest priority of CSA should be the development of an adequate program to fund scientific ballooning projects, including science studies, instrument and flight systems development, and data exploitation. The development of HQP is mainly through these projects. Due to the diversity of the ballooning community, the program should be flexible with respect to the needs of different project models and collaborations. Funding of infrastructure should not be at the expense of funding scientific balloon projects.
2) A mechanism for funding Canadian launches of small payloads (<70 kg) should be developed to provide launches in coordination with the flight needs and funding opportunities for these payloads. Canadian suppliers can meet the projected needs for these flights over the next decade.
3) An agreement between CSA and an international provider (such as NASA-CSBF) to launch large (>1 tonne) Canadian payloads should be pursued in coordination with the flight needs and funding opportunities for these payloads.

4) In order for the development of a mobile Canadian launch facility for medium sized (> 70 kg and < 1 tonne) payloads to be pursued, the following conditions should first be met:
    a. There must be a vibrant program functioning and funding the scientific balloon projects which are to be flown.
    b. For long-term stability, the funding of the launch capability must be based on its own program, rather than being tied to funding decisions of individual projects.
    c. CSA must actively pursue international partners and users for this facility for long-term sustainability.
5) The development, with active community involvement, of generic flight systems including pointing control for science instruments should be explored. The active community engagement is crucial to ensure that the systems will meet the needs of actual (current or future) funded projects.
6) Funding opportunities for community building should be provided, including meetings to share expertise, raising the profile of balloon opportunities, and support of outreach and undergraduate research opportunities (such as support for students to participate in the BEXUS program).

With the support of the community, the session chairs, Kaley Walker and Barth Netterfield, have agreed to act as community point of contacts for the development of the ballooning program.

6 REPORT FROM THE SOUNDING ROCKET SESSION

Chair and Author of this Section:

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6.1 INTRODUCTION

This chapter summarizes the discussions and recommendations from the sounding rocket session at CSA's Workshop on Suborbital Platforms and Nanosatellites, and makes recommendations to CSA management on how to proceed with revitalizing the Canadian sounding rocket program.

The sounding rocket session on day two was attended by 27 people comprised of university professors and researchers, students, industry representatives, and government personnel. Thirteen (13) of the attendees were students.

We had presentations from 10 speakers about research topics enabled by sounding rockets, lessons learned about international cooperation, launch capabilities abroad, and student programs involving sounding rockets. There was a strong international representation, with presentations from people at NASA (USA), Japan Aerospace Exploration Agency (JAXA), Andoya Rocket Range (ARR, Norway), and the Swedish Space Corporation (SSC). We also heard from a representative of Magellan Aerospace about Magellan's past sounding rocket work and its current capabilities. See Appendix A for the list of speakers and titles in this session.

The presentations and discussions reaffirm what we learned from the 2007 workshop on suborbital platforms. In 2010, the community is of the opinion that there is pent-up demand in the Canadian research community for access to sounding rocket opportunities. The community is passionate about the opportunities for scientific research, technical development, and training of the next generation of scientists, engineers, and technicians that a vigorous rocket program can provide. We have a pool of talented students who want to train on sounding rockets, and who are seeking careers in the Canadian space and aerospace industries.

The top priority is to get flying again, and to stay flying. To get flying again, we recommend that CSA provide regular, open AOs for sounding rocket missions using existing Canadian infrastructure and international collaborations. To stay flying, we recommend that CSA work with academia and industry to implement and manage capacity and resources for a sustained and openly competitive sounding rocket program.

In what follows we summarize the discussions and recommendations from the workshop as they pertain to the six questions posed by CSA that are reproduced in the backgrounder in Appendix C. These questions fall broadly under the categories of research, people, infrastructure, and funding. We also list specific recommendations and actions for CSA.

6.2 RESEARCH

We identified four broad categories of scientific research that are enabled by sounding rockets (Backgrounder, Question 1): Geospace Physics, Microgravity, Astronomy, and Solar Physics.

Geospace physics encompasses the fields of Magnetosphere-Ionosphere-Thermosphere physics, auroral physics, and plasma physics. Microgravity research includes materials, combustion, and fluid research. We include astronomy and solar physics because Canada has a history of scientific accomplishment in these areas, and these fields are still very active and indeed benefit from access to sounding rockets. Specific examples of science topics that are enabled by sounding rockets are:

- Direct measurement of auroral return currents through thermal electron drift
- 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)
- Mid-latitude ionospheric physics
- 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
- Materials Science: (microgravity): Studies of under-cooled metal solidification

In addition to the above-mentioned fields of research, the sounding rocket enables technology development and the opportunity to provide flight heritage for new satellite instruments.

6.3 PEOPLE

Sounding rockets provide relatively inexpensive opportunities to train students, technicians, engineers, post-doctoral fellows, research associates, and PIs on real space-flight hardware development (Backgrounder (Appendix C), Question 2.). Compared to satellite missions, the sounding rocket provides a relatively quick turn-around time from proposal to results. The aerospace industry needs a way to train potential new employees on many essential aspects of space missions, and sounding rockets provide an effective way to do this.

In partnership with the ESA, the SSC hosts an annual student rocket training program, called Rocket-borne Experiments for University Students (REXUS), and since Canada is a participating member of ESA, Canadian undergraduate students could apply to this program, subject to confirmation of support for their proposal from the CSA.

CaNoRock is a Canada-Norway student rocket training program for undergraduates from Canada and Norway. It is an initiative of the ARR in Norway, in collaboration with the universities of Oslo (Norway), Calgary, Alberta, Saskatchewan. The first mission was in November 2009, and consisted of a student-run launch of a CRV-7 rocket carrying student-built instruments to an altitude of 10 km. Four Canadian undergraduate students travelled to Norway and participated. CaNoRock will eventually be open to undergraduate and graduate students across Canada. CSA should be an important partner in making CaNoRock successful by providing funding to the Canadian students, and by providing opportunities to fly instruments on the larger payloads as the program moves forward.

The students at this meeting expressed a need for better communication about career opportunities. CSA should work together with academia and industry to attract and to keep new talent into the space and aerospace workforces. Ways of doing this include co-ops programs (e.g., Magellan Aerospace’s NSERC co-op program), rocket competitions (such as the Aerospace Industries Association’s “Team America Rocketry Challenge” in the U.S.), and annual (aero) space job fairs. Many companies cannot afford to travel around the country to recruit talent, so virtual job fairs should be considered.

At the graduate level, there are plans to start an annual Canadian Space Science Summer School, whereby university professors will volunteer to develop and organize week-long classes focused on a range of topics relevant to scientific space research.

The training of research associates and new faculty professors is also important, because it ensures continuity of expertise across generations, and sounding rocket missions are a relatively low-risk way to allow the next generation of leaders in academia, industry, and government to prove their mettle. We strongly endorse CSA’s initiative to establish a research chair program.

To build capacity in the Canadian space workforce, it is necessary that regular, sustained, open access to sounding rocket missions both at home and abroad be provided so that the next generation of the space workforce stays in Canada and acquire experience on different missions at different phases of those missions. Regular missions are needed to build up and maintain Canadian capacity for payload development in industry and academia, because the technicians are typically employed on a project-by-project basis, and when the projects stop coming, the technical expertise moves on.

Regarding community champions (Backgrounder (Appendix C), Question 6), the scientific community has championed the importance of the sounding rocket program through the 2007 Community Workshop on Science From Suborbital Vehicles and the Space Environment Workshop (Banff, 2009). We recommend that CSA work with academia and industry to implement and manage capacity and resources for a sustained sounding rocket program. As of April 2010, the main point of contact with the scientific community is the Space and Atmospheric Environment Advisory Committee (SAEAC) to CSA.

6.4 INFRASTRUCTURE

Canada has a significant amount of sounding rocket infrastructure in industry, government, and academia that can serve the sounding rocket user community:

- Churchill Rocket Range (currently inactive)
- Canadian ground based science networks (can be used if we were to develop portable launcher capability)
    - Scientific radars (e.g., SuperDARN, RISR)
    - Canadian GeoSpace Monitoring (CGSM)
- Bristol Aerospace Limited (Winnipeg)
    - Payload development and support
    - Mission support
    - Rocket motors (Black Brant, Excalibur, CRV-7)
    - Environmental testing
- David Florida Laboratory (DFL) (Ottawa)
    - Environmental testing
- Other
    - Instrument characterization facilities at universities (e.g., University of Calgary, University of Toronto, York University, among others)

In order to start building capacity again as rapidly as possible, the Canadian scientific community should take advantage of existing infrastructure for launching rockets outside of Canada, while relying on its existing domestic capabilities (e.g. through Bristol Aerospace) to build up payloads. There are many fixed launch ranges accessible through international partners: NASA’s Poker Flat (Alaska (AK)), Wallops Island (Virginia (VA)), White Sands (New Mexico (NM)), Kwajalein Atoll (Marshall Islands) ranges; the JAXA’s Uchinoura range; Norway’s ARR; and the Esrange facility in Sweden.

Canadian launch capability should be considered as a longer-term goal to be explored by the Canadian scientific community as it re-establishes critical mass. This should be done in collaboration with other potential users in Canada such as the Department of National Defence (DND) and industry. For example, the Churchill Rocket Range, Manitoba, is currently inactive, but in the longer term it may be useful to reactivate it in collaboration with other partners, as it is a prime location for auroral research.

International collaboration provides quality opportunities for cutting-edge science, new instrument flight opportunities, and it can lead to future flight opportunities. But Canada cannot merely fly instruments on international payloads all the time, and must show leadership with Canadian-led payloads. An example of how international collaboration can benefit Canadian missions involves high-altitude research that requires high-flying rocket vehicles, such as the Black Brant XII four-stage rocket. These vehicles use the Canadian Black Brant V motor as an upper stage, but rely on non-Canadian boosters (the Talos and the Nike) to reach altitudes greater than 1000 km. These boosters are traditionally provided by NASA on a no-exchange-of-funds basis, in return for access to instrument space and flight data by American scientists.

CSA can also facilitate international collaboration by supporting the participation of Canadian students and scientists in CaNoRock, the Canada-Norway student-exchange program. A key element of this program is that graduate students will have an opportunity to train on larger, higher-altitude rockets. Figure 6-1 summarizes the proposed launch schedule for CaNoRock rockets over the next decade.

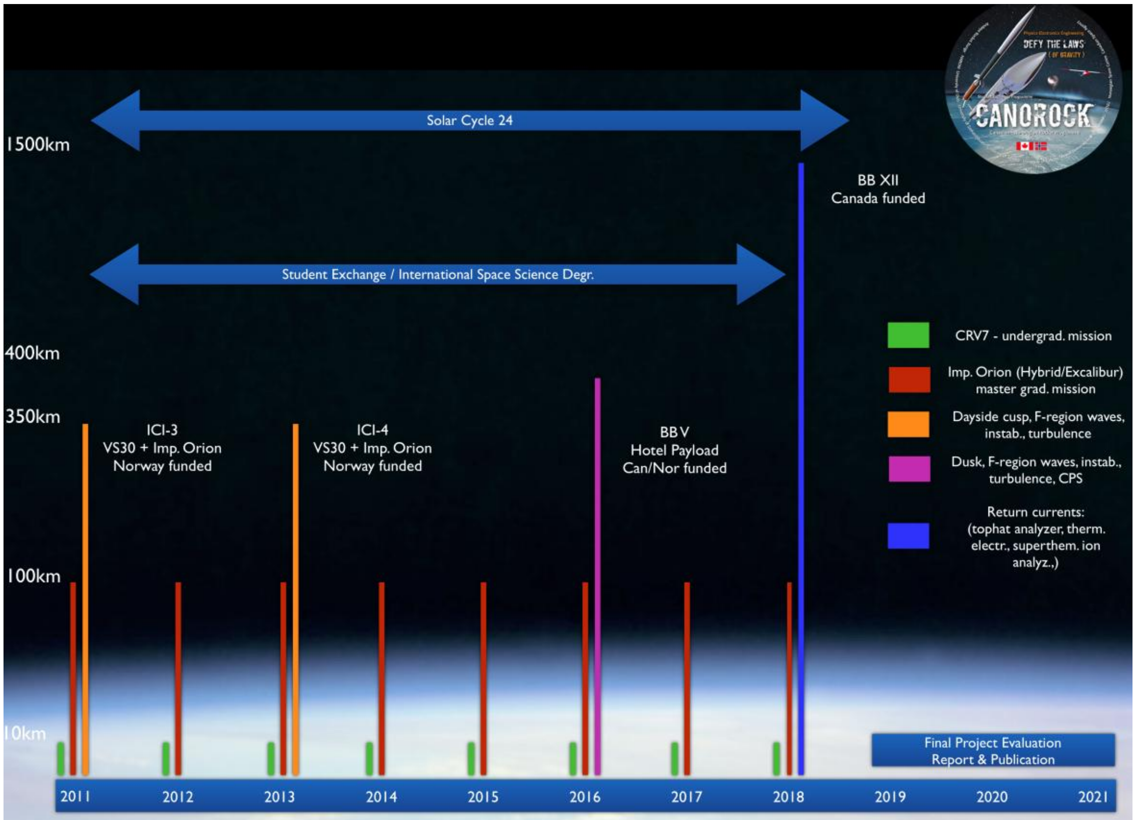

FIGURE 6-1 – PROPOSED CANOROCK MISSION TIMELINE, INCLUDING STUDENT PAYLOADS AND SCIENTIFIC FLIGHT OPPORTUNITIES

6.5 FUNDING

The current funding and administrative environment in which the community carries out sounding research is challenging. Opportunities for international collaboration are often incompatible with CSA’s schedule of AOs. There is no NSERC International Opportunity Funds (IOF), nor are there mechanisms similar to NASA’s Stand Alone Mission of Opportunity (SALMON) AOs or Unsolicited Proposal mechanisms. It is often perceived as risky for one agency to commit to a mission until another agency commits, and vice versa. A recent example of this was NASA’s Aurora Current and Electrodynamics Structure (ACES) sounding rocket mission. Because of their reputation for expertise in plasma instrumentation, Canadian scientists were invited in early 2006 to provide an ion detector and other instrumentation on ACES. As a result of the problems outlined above, in June 2008 the Canadian scientists had to withdraw their participation in the mission, and ACES went ahead without them (ACES launched in January 2009). It is hoped that CSA’s new grants and contributions and other mechanisms Flight for Advancement of Science and Technology (FAST), in the form of regular AOs, will circumvent many of these problems.

With respect to building Canadian space workforce capacity, regular, affordable rocket missions are crucial to providing end-to-end training opportunities for the next generation of scientists, entrepreneurs, engineers, and technicians to advance their skills, expertise, and experience in major space projects. It is important that this funding be sustained to provide attractive career opportunities to recruit highly talented and skilled individuals. Moreover, it is crucial that funding levels are commensurate with the value of sounding rockets as platforms for building workforce capacity and maintaining Canada's reputation for and leadership in world-class space science and technology. For example, previous Canadian sounding rocket missions, at a cost $4M to $8M each (less than 10% of the cost of a satellite mission), have provided excellent value for capacity building, technology development, and scientific return.

Further, it must be recognized that, with respect to capacity building, the value of a graduate student's education rests in part on the scientific value of the experiments she/he is training on. Funding for scientific missions must therefore include support for scientific data analysis.

The success of the Canadian sounding rocket program should be judged by its capacity to produce scientific results (e.g., dissertations and scientific publications), technological innovation (e.g., new instruments for satellite missions), and training of highly qualified personnel. Furthermore, it is important that the program be judged in comparison with similar programs in other countries, and not in comparison to other CSA programs (e.g., ground-based observation and data assimilation programs).

6.6 RECOMMENDATIONS

The list of all recommendations is available in Appendix E.3 Sounding Rocket Session.

The top priority is to get flying again, and to stay flying. We therefore recommend that CSA

1) Maintain and enhance Canada's ability to participate in international collaborations by
    a. Ensuring sufficiently frequent and regular AOs
    b. Put in place a flexible, open and timely mechanism to allow Canadian scientists to respond to international flights of opportunity
2) Participate in a scientific rocket mission at least every year combining Canadian and foreign led missions.
3) Work to increase the number of Canadian groups involved in rocket research by encouraging and enhancing student recruitment and outreach
4) CSA should provide funds, through one of its new programs, to support Canadian students participating in student rocket and science programs in Canada and internationally, such as
    a. CaNoRock, REXUS, and similar programs
    b. "Design and build" competitions
    c. Summer schools
5) Encourage rocket-borne testing of instruments destined for orbital missions but having no previous flight heritage (risk mitigation)

In addition, the government, academia and industry should work together to

6) Follow through on development of lower cost rocket platforms (e,g., Excalibur) and CRV-7 launcher capability
7) Provide a mechanism for stable employment for highly qualified personnel, including engineers, technicians and scientists in universities and industry
8) Develop university laboratory facilities and courses (senior level design projects, lab work, capstone, competitions)

7 REPORT FROM THE NANOSATELLITE SESSION

Chair and Author of this Section:

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7.1 INTRODUCTION

Nanosatellites are rapidly emerging worldwide. There are opportunities now that should be seized to ensure continued Canadian leadership. There are many Canadians actively involved in this field and in many cases, are already leaders in the international context. Previous technology demonstrations are now beginning to yield benefits to Canadian society. The following sections provide a resume of the discussion of all participants (about 80) at the nanosatellite session (List of participants in Appendix B).

7.2 RESEARCH

Nanosatellites (nanosats) are available for global coverage, short revisit times, quick technology demonstrations, high altitudes (> 450 km), long duration missions (> 6 months) and of course at low cost. Prime examples of research conducted with on a nanosatellite include:

- **Technology Demonstration**: tethered formation flight, Nanosatellite Tracking of Ships (NTS) 2. (A good example where there are new business opportunities in which Canada is ready to become a world leader.)
- **Responsive Mission**: NTS (7 months from conception to launch) in response to urgent commercial and scientific needs.
- **Atmospheric Science**: global navigation satellite system radio occultations for obtaining atmospheric profiles. There are opportunities available in this area in the next few years and Canadian technology is poised to take advantage of these opportunities.
- **Astronomy**: BRIght Target Explorer Constellation (BRITE) Constellation is a unique, innovative niche for Canada that has drawn attention from other countries that have joined the effort.
- **Instrument Maturity**: Thin Ice Clouds in Far Infra Red Experiment (TICFIRE) prototype payload and a nano-TICFIRE (as a precursor to a larger TICFIRE mission).
- **Autonomy**: PRoject for OnBoard Autonomy (PROBA)-like nanosat to demonstrate on-board autonomy and low-cost Attitude Control System (ACS)/orbit determination approaches.

In addition to these prime examples, there are many other opportunities available:

- **Looking down**: Earth Observation, Geophysics, Communications, Navigation, Surveillance, Security, Sovereignty, Defence, Resource Management, Natural Disaster mitigation, Environmental monitoring, Synthetic Aperture, Meteorology, Ocean Monitoring
- **Looking across**: Atmospheric Science (Temperature studies, Density profiles – ionosphere, ozone layer, water vapour), Aeronomy, Air Quality (Pollution – Climate Change), Satellite Tracking, Inter-satellite communication, On-orbit servicing, Refuelling another satellite, Space debris monitoring/tracking, Materials research (e.g., looking at solar cell degradation of other satellites), Collecting orbital debris
- **Looking up**: Solar and terrestrial physics – space environment and space weather – sun-earth connection, Cosmic rays, Asteroid monitoring, Surveillance and Security, Astronomy
- **Looking within**: Tech demo, Software development, Space qualification and validation
- **Extra Terrestrial Exploration**: Asteroids, Comets, Other planets

7.3 PEOPLE

Activities in the area of nanosatellites can contribute to training the next generation of space workforce in Canada. Participants provided the following list of direct and indirect outcomes related to the pursuit of nanosatellites activities

- Link industrial and scientific communities
- Academic training leading to industrial employment
- Promising scale (i.e. project size) for universities (ideal niche)
- Attract more skilled people to the sector (e.g. mitigate brain drain)
- Skills development
- Short development cycle
- Experience with working hardware for students
- Experience in planning and logistics
- More missions lead to more capacity and ideas
- Access to unique test facilities
- Create early interest in schools for space
- PR, outreach, education, awareness, national pride
- Entertainment value
- Provide more employment possibilities
- Create a consortium for nanosatellite discussion and development, bridging academia, government, and industry. It would, amongst other things, coordinate educational initiatives, facilitate student competition, publish newsletters, organize workshops and / or define new mission concepts.

Following is a list of main points of contact/champions in the Canadian community that could/would lead the effort to further develop a program in nanosats:

- Rob Zee (Director University of Toronto Institute for Aerospace Studies (UTIAS) – Space Flight Laboratory (SFL)) – key contact (see below)
- Hugh Chesser & Regina Lee (Co-Directors, YUsend Lab)
- George Zhu (Director of York Undergraduate Space Engineering Program)
- Yunlong Lin (Director of York Concurrent Design Facility)
- Chair of the Joint Committee on Space Astronomy (currently Roberto Abraham)
- Krishna Kumar (Ryerson University)
- Slavek Rucinski (University of Toronto)
- Tony Moffat (Université de Montréal)
- Jaymie Matthews (University of British Columbia (BC))
- Alfred Ng (CSA)
- Arun Misra (McGill University)

In particular, the objectives of the newly created Microsatellite Science & Technology Center (MSTC) at UTIAS align well with CSA's nanosat program. Specifically, the MSTC has the mandate to be a **national champion** for new miniature technologies and new mission concepts and is already funded by CFI and the Ontario Ministry of Research & Innovation (MRI). The MSTC should be considered the one stop solution to nanosat technology and mission development collaboration. CSA's proposed Suborbital & Nanosat program provides a natural and timely means to provide a funding source for the activities of the MSTC.

Collaboration is an important issue. Collaboration begins with mutually supporting roles. Therefore, complementarity is very important, especially in the area of nanosats. The existing centres of expertise should be leveraged to minimize cost and inefficiencies. The current centres of excellence should be identified and enhanced through complementary collaboration. For example, if someone is an expert at building a spectrometer and another is an expert at building a nanosatellite, then the two should collaborate to foster each other's area of expertise and make more missions happen.

7.4 INFRASTRUCTURE

During the workshop, the status of infrastructures for nanosatellites in Canada was explored. The infrastructures were categorized according to characteristics to complete a nanosat: buses; separation systems; payloads; components; analysis and algorithms; laboratories; launch services. It was found that some infrastructures are directly related to nanosatellites (direct relevance), meaning that the infrastructure was specifically conceived to support nanosatellites or nanosatellite missions. If the infrastructure was not primarily conceived for nanosat, it was labelled "indirect". Though the infrastructure was not design specifically for nanosat, the potential exists to use or adapt the infrastructure for nanosat or applications related to nanosat.

Another dimension of the infrastructure is its maturity: how long has it been in place and results produced on a regular basis. Though the maturity was mainly evaluated on a qualitative basis, the participants at the nanosat section felt infrastructures could be categorized that way. At the other end of the maturity spectrum, an infrastructure was labelled “nascent”. Table 7-1 summarizes the infrastructure discussion at the workshop, recognizing that it is not exhaustive.

Concerning what infrastructure upgrading, building or replacing is needed in Canada to enable optimal access to nanosatellites, (Backgrounder (Appendix C), question 4) the participants listed the following:

- Create and expand ground station network
- Develop Canadian launch capability
- Provide more radiation labs across the country
- Provide more employment possibilities
- Facilitate student competition

TABLE 7-1 – SUMMARY OF INFRASTRUCTURES THAT PROVIDE NANOSATELLITE SYSTEMS

Maturity of Infrastructures to Provide Nanosatellite Systems				
	Direct & Mature	**Indirect & Mature**	**Direct & Nascent**	**Indirect & Nascent**
Separation Systems	UTIAS/SFL XPOD for 1U, 2U, 3U CubeSats, XPOD GNB, XPOD Duo Calpoly (USA): P-POD Mk.2 (DM) for CubeSats.			
Nanosatellite Buses	UTIAS/SFL CanX-2 bus, 3.5kg, 10x10x34cm, Generic Nanosatellite Bus (GNB), 7kg, 20x20x20cm, NEMO bus, 15kg, 20x20x40cm	Bristol (Ottawa): Quicksat development	York U: YUS end CubeSat, 40s-40kg micros at (IN), Tethered nanos at concept (DN). RMC: CubeSat program (DN)	York U: 40s-40kg micros at (IN),
Launch Services, Brokering	UTIAS/SFL Nanosat Launch Service (NLS), NLS-1 through NLS-5 have flown (DM). Calpoly (USA): ad-hoc, one or two successful campaigns		ISIS (Netherlands): ad-hoc, one successful campaign	
Payloads	UTIAS/SFL GPS receivers, optics (DM) U Calgary: GNSS payloads, navigation capability, space physics payloads York U: spectrometers, science instruments, payloads, space science program	U Alberta: space physics payloads, sensors (temp, mechanical, pressure) INO: Optical payloads design, manufacture, test, qualify RMC: Defence research, environmental monitoring, space situational awareness, surveillance, space physics, astrophysics COM DEV: Communication payloads, optics, spectrometer, power components Optech: Optics, LiDAR		
Analysis and Algorithms	UTIAS/SFL: Formation control algorithms, high performance attitude control (DM)	McGill U: Orbit, attitude and formation control algorithms (IM) NGC: Guidance, Navigation, and Control design and implementation (IM) McGill U: Orbit, attitude and formation control algorithms (IM) Ryerson U: orbits, attitude and formation control (sensors, actuators, controllers (IM))		
Components	UTIAS/SFL components for all subsystems (DM) Sinclair Interplanetary: Parts manufacturing, design, reaction wheels, star tracker (DM		Ryerson U: sensors and actuators (DN)	

7.5 FUNDING

The following indicates what investments are recommended to Canada to meet these goals.

- Provide stable funding:

  There are four aspects to this:

  1. Generate mission ideas and enabling payloads, Contribute $500K/year to the MSTC operating budget to ensure that this national center has the resources needed to fulfill its mandate of developing new enabling technologies, payloads, and instruments for nanosats, and establishing the feasibility of new missions. The budget will be used to stimulate technology development and attract the involvement of new principal investigators. This will ensure that nanosatellite expertise and infrastructure at the MSTC is maintained. Part of the budget will be used to fund an annual workshop (a MSTC activity) involving potential PIs from across Canada. It would also be spent on technology development (devices, instruments) and feasibility studies in collaboration with PI universities by enabling the MSTC to dedicate 2-3 professionals to this activity, purchase materials, pay for travel and living to/from other universities, and support students at the MSTC and PI universities. This will ultimately enable the steady supply of mission concepts (supported by mature enabling technologies) for CSA's FAST program. The support to the MSTC will also guard against obsolescence and ensure that technology readiness of nanosat platforms is maintained.
  2. Set up appropriate budget in relation to nanosatellites, Set up the FAST program to fund at least one nanosatellite mission every 2 years. A mission based on SFL's 15 kg Nanosatellite for Earth Monitoring and Observation (NEMO) bus, for example, could cost around $2.5M. A mission based on SFL's 7 kg Generic Nanosatellite Bus (GNB) could cost around $1.5M. It is recommended that CSA set aside $1.5M per year for FAST nanosat projects. This would enable, roughly, one NEMO mission every two years, or two GNB missions every two years. Alternatively, setting aside $1M per year for FAST nanosat projects would extend the cycle to every three years. Reducing the frequency further would potentially have an impact on sustainability.
  3. Manage launch cost risk, as launch costs are subject to variability. These need to be managed separately, if possible. For missions based on SFL's NEMO bus, launch costs can range from $700K-$1M. For Missions based on SFL's GNB, launch costs can range from $500K-700K. Past experience indicates that launch costs can escalate 30-50% without much warning. These are coarse estimates only – savings may be possible through the SFL Nanosat Launch Service (NLS).
  4. Provide support for operations and ground station maintenance. By setting aside $100K per year, it will be possible to support operations for the nanosatellites prepared under the FAST program. This amount could also be used to maintain ground stations that are supporting nanosat operations in Canada.

- Fund specific science and Technology projects (identify key areas for research: e.g., atmospheric science)
- Entice industrial grants, nanosatellite stimulus funding

- Help in establishing more entry-level jobs-internships for new grads, Expanding co-op programs
- Reach a balanced approach and encourage collaboration between industry and academia
- Promote space science and technology
- Encourage other government departments to make use of space technology
- Enhance public relations and educational outreach, increase quality and quantity (increase to significant percent >1% of total budget, as at NASA and ESA)
- Catch up to per capita funding from other key space agencies (NASA, ESA, JAXA)

7.6 RECOMMENDATIONS

The list of all recommendations is available in Appendix E.4 Nanosatellite Session.

1) Canada already has existing infrastructure in nanosatellites that is internationally recognized. Several nations are already taking advantage of Canadian nanosat technology and expertise at UTIAS/SFL – Canada should do the same and exploit SFL nanosat technology and expertise for targeted science and technology missions.
2) Support the MSTC that has already been mandated with championing new initiatives by establishing synergies with the CFI-funded MSTC to develop technologies, payloads, instruments and mission concepts in collaboration with established university groups (Calgary, York, Lethbridge, New Brunswick, Toronto, etc). Utilize SFL's very active Nanosat Launch Service.
3) CSA should proceed with its program in suborbital & nanosatellites to provide ideal opportunity to fund initiatives championed by the MSTC.
4) Research Infrastructure Program (RIP) – CSA should direct new infrastructure funding to complementary facilities and sustain existing centre of excellence through the new RIP presented at the workshop
5) FAST – CSA should proceed with the new program FAST which can help fund new, fast missions, but new ideas are needed:
    a. BRITE
    b. Nano-TICFIRE
    c. "PROBA" like autonomy experiments on a nanosat
    d. GPS radio occultation – global mapping of atmospheric properties
    e. Tethered nanosatellite, electrodynamic tether

8 CSA WORKSHOP – INTEGRATED CONCLUSIONS

While the individual recommendations of each of the sessions on specific platforms are important as stand-alone conclusions for consideration by CSA, there are a few over-arching issues that emerge from the Workshop. These are summarized below to provide guidance to CSA in its future planning for capacity development.

1) **The value of cost effective rapid means of accessing space as a means of building capacity**

   The research community commends CSA for its leadership in promoting cost effective access to microgravity environments, near-space and space on time frames commensurate with graduate student projects. The provision of, and access to, low cost platforms is a critical component of rebuilding space science capacity – both academic researchers and individuals trained through space science and engineering for careers in industry and government.

2) **Catalyzing the pipeline from undergraduate to graduate**

   Opportunities for graduate studies and a career in space science and engineering are not easily visible to the undergraduate where the programming tends to be structured around discipline lines. CSA support of access to programs such as CaNoRock, REXUS and BEXUS is particularly valuable in stimulating interest in graduate work in space sciences and engineering and fosters recognition of the utility of balloons and rockets as platforms for research. Given that NSERC and CIHR do not support undergraduate research or these types of activities, CSA fulfills a unique niche in providing support for such initiatives.

3) **A planning horizon for missions and research initiatives**

   The research community is requesting a long-range, frequent and predictable process for AOs, including budgetary envelopes that are publicly available, that offer the opportunity for researchers to plan missions and compete for CSA support of the most meritorious initiatives with clear timelines for the submission of proposals and decisions on funding. This is a key condition for the continued employment of Research Associates and the planning of graduate student projects that respond to the CSA priority of capacity development.

4) **A balanced program of support – recognizing the inter-dependence of research funding, personnel support (HQP and research associates), and research infrastructure.**

   The research community recognizes the catalytic power of infrastructure investments in promoting research in space science and engineering. At the same time, in the absence of predictable funding opportunities for small and larger missions (see previous discussion of the planning horizon) there is scant prospect of frontier research and research training proceeding without a balanced portfolio of support that embraces research support, personnel support and research infrastructure. For this reason, there is enormous reluctance on the part of the research community to endorse support of a major infrastructure initiative in the absence of a commitment to a balanced mission and research support program.

5) Coherence and collaboration among funding agencies

Recognizing that no one agency has the resources to fully fund a major space science initiative from cradle to grave, it is critical that there be greater synergy and cooperation among funding agencies, in particular CSA, CFI and NSERC, than in the past. There is also value in the inter-agency leverage of support – where the priorities identified by any one agency converge with those of others. This will require more flexibility in decision-making structures and programming of all agencies than has been exhibited in the past, but is critical for a full return on the research investment.

6) Enable Canadian leadership of international missions

Canada has a legacy of strength in space science, but is suffering from the fact that it has not been in a position to lead international missions in recent years. The community argues strongly for getting Canadian researchers flying again and in some cases, providing them with the opportunity to lead international missions.

7) Strategic support for new infrastructure

The community welcomes the overtures from CSA to partner with the research community in a limited number of priority proposals to CFI for research infrastructure that complements that already in existence. At present the challenge of finding matching funds, and even more that of accessing adequate long-term operations and maintenance support, mitigates against acquiring facilities that are regional and national in scope. The research community experience with PEARL is a case in point. As indicated above, such infrastructure acquisitions must be developed in the context of predictable program support for missions and research and long-range plans of the various user communities.

8) Strategic support for existing infrastructure

CSA is urged to provide support for existing centres of excellence and infrastructure to optimize return on investments and maintain currency of the resources, especially where there are unique facilities that serve the national research community. These centres can also support national networks of researchers and catalyze the development of mission concepts.

9 CONCLUDING REMARKS

The attendance at the 2010 workshop on Suborbital platforms and Nanosatellites demonstrates that these research platforms are in high demand as a means to allow pertinent and excellent research to be conducted at a lesser cost than a space mission and at a fraction of the time needed to get the results. Researchers retain an active interest in these platforms and are conscious that excellent research can be conducted on them. Participants from industry, the academic world, government and not-for-profit organizations collaborated together to produce significant recommendations to CSA.

9.1 THANKS

The attendance at the workshop was very encouraging. It brought together participants with different interests for the platforms under discussion. Thank you to all attendees for their eagerness to share their ideas and their generosity in taking time out of busy schedules to participate in this valuable exercise.

Thank you to the speakers who gave us presentations on the status of each platform as we opened the workshop. Thank you for the participants who travelled from France, Italy, Sweden, Norway, and the USA to share with us their expertise and knowledge.

Thanks to CSA for making their Conference Centre available for this important workshop.

10 ACRONYMS AND ABBREVIATIONS

ACES	Aurora Current and Electrodynamics Structure
ACS	Attitude Control System
AFM	Atomic Force Microscopy
AK	Alaska
AO	Announcement of Opportunity
ARR	Andoya Rocket Range, Norway
ASI	Agenzia Spaziale Italiana
BC	British Columbia
BEXUS	Balloon-borne Experiments for University Students
BRITE	BRIght Target Explorer Constellation
CaNoRock	Canada-Norway Rocket
CCRS	Canada Centre for Remote Sensing
CFI	Canadian Foundation for Innovation
CFCAS	Canadian Foundation for Climate and Atmospheric Science
CGSM	Canadian GeoSpace Monitoring
CIHR	Canadian Institutes of Health Research
CNES	Centre national d'études spatiales (Agence spatiale française)
CSA	Canadian Space Agency
CSBF	Columbia Scientific Balloon Facility
DFL	David Florida Laboratory
DND	Department of National Defence
EC	Environment Canada
ER2	Lockheed U-2, a single-engine, very high-altitude reconnaissance aircraft
ESA	European Space Agency
FAAM	Facility for Airborne Atmospheric Measurements
FAST	Flight for Advancement of Science and Technology
FRL	Flight Research Laboratory
GC	Government of Canada
G&C	Grants & Contributions
GNB	Generic Nanosatellite Bus
GPS	Global Positioning System
HQP	Highly Qualified Personnel
INO	Institut national d'optique
IOF	International Opportunity Funds

ISS	International Space Station
JAXA	Japan Aerospace Exploration Agency
LIDAR	Light Detection and Ranging
MANTRA	Middle Atmosphere Nitrogen TRend Assessment
MOA	Memorandum of Agreement
MOU	Memorandum of Understanding
MRI	Ministry of Research & Innovation
MSTC	Microsatellite Science & Technology Center
NASA	National Aeronautics and Space Administration
NAWX	NRC Airborne W and X-band polarimetric Doppler radar system
NEMO	Nanosatellite for Earth Monitoring and Observation
NLS	Nanosat Launch Service
NM	New Mexico
NRC	National Research Council of Canada
NTS	Nanosattelite Tracking of Ships
NSERC	Natural Sciences and Engineering Research Council of Canada
OGD	Other Government Departments
PDF	Post-Doctoral Fellows
PEARL	Polar Environment Atmospheric Research Laboratory
PI	Principal Investigators
PROBA	PRoject for OnBoard Autonomy
REXUS	Rocket-borne Experiments for University Students
RIP	Research Infrastructure Program
RISR	
SAEAC	Space and Atmospheric Environment Advisory Committee
SALMON	NASA's Stand Alone Mission of Opportunity
SAR	Synthetic Aperture Radar
SEM	Scanning Electron Microscope
SFL	Space Flight Laboratory (University of Toronto)
SIL	Scientific Instruments Limited
SSC	Swedish Space Corporation
SWARM	ESA Mission; a constellation of three satellites in three different polar orbits
SWIR	Short Wave Infra Red
TEM	Transmission Electron Microscope
TICFIRE	Thin Ice Clouds in Far Infra Red Experiment
UAV	Unmanned Aerial Vehicle

UK	United Kingdom
U.S.	United States
UTIAS	University of Toronto Institute for Aerospace Studies
UTLS	Upper Troposphere – Lower Stratosphere
UV	Ultra-violet
VA	Virginia

APPENDICES

A WORKSHOP SCHEDULE

TABLE A-1 – WORKSHOP SCHEDULE

Workshop Schedule - Plenary Room DAY 1			
Time	**Event**	**First Name, Last Name**	**University/Organization**
Day 1: Wednesday, April 14, 2010			
11:15 – 13:00	***Registration; Lunch***		
13:00 – 13:15	Introduction – Welcome	LOUISE BEAUCHAMP	Canadian Space Agency
13:15 – 15:00	Welcome and Update on CSA programs	STEVE MCLEAN DAVID KENDALL ALAIN BÉRINSTAIN LOUISE BEAUCHAMP	Canadian Space Agency
15:00- 15:30	Q&A	ALL	
15:30 - 16:00	***Afternoon Break***		
16:00 – 18:00	**General Presentations on each platforms**		
16:00 – 16:30	Aircraft status	DAVE HUDAK ANDREW HIGGINS	EC McGIll
16:30 – 17:00	Balloon status	TOM MCELROY BARTH NETTERFIELD	Environment Canada U. Toronto
17:00 – 17:30	Nanosatellites status	A. NG	Canadian Space Agency
17:30 – 18:00	Sounding Rockets status	G. JAMES (invited)	
18:00 – 19:30	***Cocktail***		

Workshop Schedule - Plenary Room DAY 2			
	Workshop Schedule - Aircrafts - Room 7A-101		
	Co-Chair: Dr. Andrew Higgins		
Time	**Event**	**First Name, Last Name**	**University/Organization**
Day 2: Thursday, April 15, 2010			
08:00 – All day	Registration & information	MARIA MARTINEZ	CSA
08:45 – 09:00	Opening – Welcome	ANDREW HIGGINS	McGill University
09:00– 09:20	Capabilities and operational conditions of the NRC Falcon-20 parabolic aircraft	T. LESLIE C. SWAIL	NRC Flight Research Laboratory
09:20– 09:40	Parabolic fligths with A300 ZERO-G: aircraft capabilities and opportunities	FRÉDÉRIC GAI	NOVESPACE
09:40– 10:00	The Role of Gravity in nanowire growth	CARLOS FERNANDEZ HARRY RUDA	U. of Toronto

10:00 – 10:15	***Morning Break***		
10:15 – 10:35	Rapid Solidification of Al-Cu, Al-Fe and Al-Ni particles under diffusion-limited conditions	HANI HENEIN	U. of Alberta
10:35– 10:55	Gravitational Effects in Electropolymerization: Targeting Materials with Improved Nonlinear Optical (NLO) Properties	X. ROY M. ROBERTS M. WOLF M. MACLACHLAN	U. of British Columbia
10:55– 11:15	Laminar Flame in Nonvolatile Solid Particulate Suspensions	FRANÇOIS-DAVID TANG S. GOROSHIN ANDREW HIGGINS	McGill U.
11:15 – 11:35	Electromagnetic forces in particle dust clouds	CLAUDE RIOUX R. SLOBODRIAN	U. of Laval
11:35 – 11:55	Gravitational effect in phase separation process	M. MOVASSAT N. ASHGRIZ	U. of Toronto
11:55 – 13:15	***Lunch***		
13:15 – 15:15	Breakout Session: *Discussions*		
15:15 – 15:30	***Break & Group Picture***		
15:30 – 17:30	Breakout Session: *Summaries*		

Workshop Schedule - Aircrafts - Room 4

Co-Chair: Dr. D. Hudak

Time	Event	First Name, Last Name	University/Organization
Day 2: Thursday, April 15, 2010			
08:00 – All day	Registration & information	MARIA MARTINEZ	
08:45 – 09:00	Opening – Welcome	DAVE HUDAK	Environment Canada
09:00 – 09:20	NRC Airborne Research: Facilitates and Research Focus	MENGSITU WOLDE	Institute for Aerospace Research, National Research Council
09:20 – 09:40	The Convair 580 SAR Facility – Recent Activities and Future Opportunities	CARL BROWN	Emergencies Science and Technology Section, Environment Canada
09:40 – 10:00	Research aircraft applications: Processes, retrieval algorithms and verification	STEWART COBER	Cloud Physics and Severe Weather Research Section, Environment Canada
10:00 – 10:20	Airborne measurements for the validation of satellite sea ice products	CHRISTIAN HAAS	Dept. Earth & Atmospheric Sciences and Geophysics, University of Alberta

10:20 – 10:35	***Morning Break***		
10:35 – 10:55	The combined role of aircraft and space-based platforms in assessing aerosol indirect radiative forcing	RICHARD LEAITCH	Climate Chemistry Measurements Research Section, Environment Canada
10:55 – 11:15	Aircraft Atmospheric Research and Planetary Exploration	JIM WHITEWAY	Centre for Research in Earth and Space Science, York University
11:15 – 11:35	EC Aircraft Measurements of Atmospheric Composition and Chemistry	TOM MCELROY	Experimental Studies Division, Environment Canada
11:35 – 11:55	Aircraft Observations of the Lower Atmosphere and Surface Exchange Processes	JENNIFER MURPHY	Department of Chemistry, University of Toronto
11:55 – 12:15	Utility of aircraft and satellite measurements: Examples from STAR and UNSTABLE	JOHN HANESIAK	Department of Environment and Geography, University of Manitoba
12:15 – 12:35	How can aircraft measurements tell us about the source/sink distribution of greenhouse gases?	JOHN LIN	Waterloo Atmosphere-land Interactions Research Group, U. of Waterloo
12:35 – 13:15	***Lunch***		
13:15 – 15:15	Breakout Session: *Discussions*		
15:15 – 15:30	***Break & Group Picture***		
15:30 – 17:30	Breakout Session: *Summaries*		

Workshop Schedule - Nanosatellites - Room 2

Chair: Dr. A. Moffat

Time	Event	First Name, Last Name	University/Organization
Day 2: Thursday, April 15, 2010			
08:00 – All day	Registration & information	MARIA MARTINEZ	
08:45 – 08:55	Opening – Welcome	TONY MOFFAT	
08:55 – 10:20	**Design and Construction**		
08:55 – 09:20	Overview of SFL missions and the new Microsatellite Science and Technology Center (MSTC)	ROBERT ZEE	U. of Toronto
09:20 – 09:35	The YuSEND (York University Space Engineering Nanosatellite Demonstration) Program	HUGH CHESSER	York U.
09:35 – 09:50	Tethered nanosatellites	GEORGE ZHU	York U.
09:50 – 10:05	Technology Demonstration Missions for Orbit and Attitude Control of Nanosatellites	KRISHNA KUMAR ARUN MISRA	Ryerson U. McGill U.
10:05 – 10:20	A 40s (40kg, 40Watts, 40Km, 40days) Small Balloon/Satellite Platform for Space Science Research in Space and from Space	YUNLONG LIN	York U.
10:20 – 10:35	PROBA nanosattelites - design capabilities for autonomous guidance, navigation and control.	Jean de la Fontaine	NGC Aerospace

10:35 – 10:50	***Morning Break***		
10:50 -11:05	**Earth Observation**		
10:50 -11:05	The needs of suborbital platforms for Earth observation precursor missions	FRANÇOIS CHATEAUNEUF	INO
11:05 – 11:20	**Navigation**		
11:05 – 11:20	Navigation and atmospheric profiling based on GNSS technologies for nanosatellite missions	SUSAN SKONE	U. of Calgary
11:20 – 12:35	**Astronomy**		
11:20 – 11:35	MOST (Microvariability and Oscillations of STars) - Canada's first astronomy space telescope	SLAVEK RUCINSKI	U. of Toronto
11:35 – 11:50	BRITE (Bright Telescope Explorer)-Constellation, the world's first nanosat space telescope	TONY MOFFAT	U. of Montreal
11:50 – 12:05	Pre-launch testing of the BRITE nanosat telescope	STEFAN MOCHNAKI	U. of Toronto
12:05 – 12:20	NASA/Ames: Observing planet transits with BRITE	JASON ROWE	
12:20 – 12:35	BRITE and chaotic pulsation in Cepheids	DAVID TURNER	St-Mary's U.
12:35 – 13:15	***Lunch***		
13:15 – 15:15	Breakout Session: *Discussions*		
15:15 – 15:30	***Break & Group Picture***		
15:30 – 17:30	Breakout Session: *Summaries*		

Workshop Schedule - Sounding Rockets - Room 3

Chair: Dr. J. Burchill

Time	Event	First Name, Last Name	University/Organization
Day 2: Thursday, April 15, 2010			
08:00 – All day	Registration & information	MARIA MARTINEZ	
08:45 – 09:00	Opening – Welcome	JOHNATHAN BURCHILL	
09:00 – 10:50	**Sounding Rocket Science**		
09:00 – 09:25	Exploring Geospace Using NASA Sounding Rockets	ROBERT PFAFF (invited)	NASA Goddard Space Flight Center
09:25 – 09:50	Japanese Sounding Rocket Activities	ABE TAKUMI (invited)	Japan Aerospace Exploration Agency
09:50 – 10:05	International collaboration in sounding rocket experiments: the benefits, potentials and limitations	ANDREW YAU	U. of Calgary
10:05 – 10:20	Non-Equilibrium Solidification of Al Alloys in a Microgravity Environment	HANI HENEIN	U. of Alberta
10:20 – 10:35	Active, two-point plasma wave experiments on OEDIPUS	GORDON JAMES	Communications Research Centre
10:35 – 10:50	Ionospheric Thermal Electron Currents	JOHNATHAN BURCHILL	U. of Calgary
(15 min.)	GMI Magnetometer Test Flight on CaNoRock-1: Think Small?	DAVID MILES	U. of Alberta

10:50 – 11:05	***Morning Break***		
11:05 – 12:30	**Sounding Rocket Capabilities**		
11:05 – 11:20	Magellan's suborbital rocket capabilities	DIANE KOLTELKO	Magellan Aerospace
11:20 – 11:35	Andoya Rocket Range capabilities, CaNoRock	KOLBJORN DAHLE	Andoya Rocket Range
(15 min.)	Swedish Space Corporation, BEXUS/REXUS	OLLE PERSSON	Swedish Space Corporation
11:35 – 12:30	Begin discussions	EVERYONE	
12:30 – 13:15	***Lunch***		
13:15 – 15:15	Breakout Sessions, discussions		
15:15 – 15:30	***Break & Group Picture***		
15:30 – 17:30	Breakout session, summaries		

Workshop Schedule - Balloons - Room 1

Co-Chairs:Dr. K. Waler & Dr. B. Netterfield

Day 2: Thursday, April 15, 2010			
08:00 – All day	Registration & information	MARIA MARTINEZ	
08:45 – 09:00	Welcome – Introduction	BARTH NETTERFIELD KALEY WALKER	U. of Toronto
09:00 – 09:45	**Talks on Science and Needs - ASTRONOMY**		
09:00 – 09:10	The EBEX balloon-borne experiment for measuring the polarization of the microwave background radiation	FRANÇOIS AUBIN	U. McGill
09:10 – 09:20	Balloon-borne optical telescopes	BARTH NETTERFIELD	U. of Toronto
09:20 – 09:30	Spider: a sub-millimeter polarimeter for inflation, dust and the epoch of reionization	NATALIE GANDILO	U. of Toronto
09:30 – 09:40	BLASTpol: a sub-millimeter polarimeter for determination of impact of magentic fields in star formation	LAURA FISSEL	U. of Toronto
09:45 – 10:30	**Talks on Science and Needs - ATMOSPHERIC SCIENCE**		
09:45 – 09:55	Requirements for balloon-borne infrared spectrometers: Small, Medium and Large.	PIERRE FOGAL	Environment Canada
09:55 – 10:05	Targeted Measurements and Instrument Miniaturization	BRIAN SOLHEIM	York U.
10:05 – 10:15	A role for small-balloon capability in the Canadian space science program	GORDON SHEPHERD	York U.
10:15 – 10:25	Limb Imaging of Aerosols (LIMA) - Observations of aerosols from a high-altitude balloon platform	MARIANNA SHEPHERD	York U.
10:25 – 10:35	A proposal for a balloon campaign for the Minature Earth Observing Satellite (MEOS)	JAMES SLOAN	U. of Waterloo
10:35 – 10:45	Synergy between ballooning and satellite missions - validation and instrument development	KALEY WALKER	U. of Toronto
10:45 – 10:55	Balloon based diagnostics of space based instrumentation	TOM MCELROY	Environment Canada

10:55 – 11:10	***Morning Break***		
11:10 – 12:30	**Discussion of Science and Needs**		
12:30 – 13:15	***Lunch***		
13:15 – 15:15	**Talks and Discussion on Capabilities**		
13:15 – 13:25	Ballooning capabilities that exist within Scientific Instrumentation Ltd. of Saskatoon	DALE SOMMERFELT	Scientific Instrumentation Ltd.
13:25 – 13:35	Launch Capabilities of Columbia Scientific Balloon Facility (CSBF)	MARK HALPERN	U. of British Columbia
13:35 – 13:45	ASI Stratospheric balloon program	ENRICO FLAMINI	Agenzia Spaziale Italiana
13:45 – 13:55	A Canadian-Based Turnkey Mission Service For Stratospheric Payloads.	ARNY SOKOLOFF	Continuum Aerospace Inc.
13:55 – 14:05	Status of the French balloon programme and possible cooperation with Canada	CLAUDE CAMY-PEYRET	CNRS. France
14:05 – 14:15	Esrange Launch Facilities and Student Program	OLLE PERSSON	Swedish Space Corporation
	Discussion on Capabilities		
15:15 – 15:30	***Break & Group Picture***		
15:30 – 17:30	Completing Discussion and Summarizing Needs/Requirements for Ballooning		

Workshop Schedule - Plenary Room DAY 3			
Time	**Event**	**First Name, Last Name**	**First Name, Last Name**
Day 3: Friday April 16, 2010			
	Registration & Information	MARIA MARTINEZ	CSA
08:00 – Noon	Breakout Session Summary: *Presentation #1*	Chair	
09:00 – 09:45	Breakout Session Summary: *Presentation #2*	Chair	
09:45 – 10:30	***Morning Break***		
10:30 – 10:45	Breakout Session Summary: *Presentation #3*	Chair	
10:45 – 11:30	Breakout Session Summary: *Presentation #4*	Chair	
11:30 – 12:15	Discussion Forum (Panel)	All	All
12:15 – 12:45	Closing Remarks	DAVID KENDALL ALAIN BÉRINSTAIN LOUISE BEAUCHAMP	CSA
12:45 – 13:00	***End of Workshop***		

University & College

B LIST OF REGISTERED PARTICIPANTS BY TYPE OF INSTITUTION

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Solheim	Brian	York University
Sterling	George Earl Grant	University of British Columbia
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Dahle	Kolbjørn Blix	Andoya Rocket Range
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Lefebvre	Luc	Canadian Space Agency
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Nikanpour	Darius	Canadian Space Agency
Pellerin	Tony	Canadian Space Agency
Peruzzini	Walter	Canadian Space Agency
Potvin	Marie-Josée	Canadian Space Agency
Ramirez	José Miguel	Canadian Space Agency
Saraf	Sidharth	Canadian Space Agency
Vigneault	André	Canadian Space Agency
Vincent	Philippe	Canadian Space Agency
Vukovich	George	Canadian Space Agency
Wilkinson	Ronald	Canadian Space Agency

C WORKSHOP BACKGROUNDER

The following section includes the English version of the Workshop Backgrounder as provided to the participants.

Workshop Backgrounder
Sub-orbital Platforms and Nanosatellites

Specific Objectives of the 2010 Workshop Sessions

1. What research areas are enabled by these platforms (over and above issues addressed in the 2007 Sub-orbital and 2006 nanosatellite Workshops and that are reproduced below)?
2. How can the proposed activities utilizing these platforms best contribute to training the next generation of the space workforce in Canada?
3. What infrastructure exists in Canada and/or internationally that enables access to these platforms?
4. What infrastructure upgrading, building or replacing is needed in Canada to enable optimal access to these platforms?
5. What investments by the Government of Canada would you recommend to meet CSA's goals? (Infrastructure and/or research investments)
6. Who are the main points of contact /champions in the community who could or would lead the effort to further develop a program in this area?

Vision for the Sub-orbital Program (From the 2007 Workshop) [1]

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 [*aircraft, high-altitude balloons, sounding rockets*]. 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.

The CSA Context - 2010

The CSA recognizes that researchers need access to space at frequent intervals to hone their skills, generate research results at a fast pace and train highly qualified people in a reasonable period of time. It has identified rapid and cost-effective access to space and sub-orbital platforms as a priority for future CSA programs. To this end, it is seeking to enhance its programming to facilitate access to sounding rockets, balloons, aircraft and nanosatellites as research platforms and for technology development, validation and demonstration.

As a follow up to the 2007 Workshop recommendations (as well as the 2004 nanosatellite Workshop) the CSA is implementing a new grants and contributions program to support regular campaigns. The new CSA program intends to provide funding for:

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[1] This vision was developed by the research community involved in the 2007 Workshop. See final report of the Community Workshop on Science from Suborbital Vehicles. February 1 and 2, 2007. http://www.atmosp.physics.utoronto.ca/~workshop/CWSSV_final_report.pdf

- Instrumentation development and testing/validation related to flight opportunities in Canada and abroad undertaken by Canadian universities and industry – recognizing the value for graduate training.
- The costs associated with research campaigns that are carried out through Canadian or international collaborations.

In addition, and subject to the outcomes of the discussions during the 2010 Workshop, the CSA intends to provide funding, in partnership with other sources, for the development and maintenance of a Canadian-based balloon launch facility. The funding level for these activities has yet to be finalized.

1. Context for Discussions - Sounding Rockets

This breakout session provides the opportunity for potential users of sounding rockets to provide input to the CSA on an action plan in the context of CSA's future plans in the areas of capacity building and mission support. Foremost among the priorities is for the community to identify which international collaborations would best serve the research and training interests of the Canadian community using this research platform. The recommendations emanating from the 2007 Workshop upon which this discussion builds are listed at the end of this section.

Sounding rockets offer users the following benefits:

- Access to space at altitudes not accessible to satellites or balloons (e.g. 50 km - 200 km); this means in-situ upper atmosphere measurements, or remote-sensing EUV, X-rays, etc. for solar and astrophysical research
- Training of highly qualified personnel (both students and Principal Investigators)
- Profiling of upper atmosphere vertical structure
- Proof-of-concept testing of existing or potential satellite instruments (flight heritage)
- High data rates (>1 MB/sec)
- Low velocity compared to satellites allows investigation of fine-scale spatial structure
- Depending on the rocket, 3-13 minutes of low gravity – usually with levels of $\leq 10^{-4} g_0$
- Minimum safety constraints for the experiments, particularly useful for graduate training
- Payload attitude control (typically spin-stabilized)
- Sensors can be deployed on long booms (e.g., 8 m radio antennas are common)
- Multiple deployable sub-payloads
- Trajectory shaping
- Tethered payload experiments
- Possibility of interactive experiment operation from the launch site or via ISDN lines
- Extensive user infrastructure (including laboratories, offices, workshop, storage, accommodation) at established launch sites such as Esrange in Kiruna, Sweden; Andoya and Svalbard, Norway; Poker Flat, Wallops Island, Kwajalein Atoll (Marshall Islands), USA; Kagoshima Space Center, Japan, Australia, India, etc.
- The possibility of access to the experiment installation until just before the launch and rapid retrieval of samples after the launch.

For more information on Canada's sounding rocket heritage and specific examples of the benefits of the sounding rocket platform, please refer to *Knudsen and Wallis*, 1998, *Physics in Canada*.

One aspect in the development of a sounding rocket program is the designation of the parameters of the sounding rocket and its associated systems. The Workshop breakout group should also advise the CSA on how data will/should be managed and by whom – e.g. data repositories, archiving and accessibility regimes. [2]

Examples of research questions of interest to Canadian scientists that can be (or are being) addressed by sounding rockets – from 2007 Workshop

- Direct measurement of auroral return currents through thermal electron drift (*c.f.* 2007 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

Sounding Rocket Recommendations - from 2007 Workshop

1. Maintain and enhance Canada's ability to participate in international collaborations by
   a) ensuring sufficiently frequent and regular AO's
   b) forming or supporting working groups with both agency-level and scientist-level participation to develop bilateral collaborations in specific disciplines and
   c) 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.

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[2] For example – see http://www.wdc.rl.ac.uk/wdcmain/europe/ratmosphere.html; http://www.wdc.rl.ac.uk/wdcmain/usa/atmosgas.html

It should also be pointed out that three Canadian universities – Calgary, Alberta and Saskatchewan – have recently entered into a collaborative arrangement with the University of Oslo, the Andøya Rocket Range and the Norwegian Centre for Space-related Education (NAROM). CaNoRock is proposed as a ten-year program which targets the training of undergraduate and graduate students in experimental space science, as well as the flight of research sounding rockets to study magnetosphere-ionosphere-atmosphere electrodynamics, including the generation of the aurora. [Ref.: http://www.lpi.usra.edu/meetings/nsrc2010/pdf/4061.pdf]

2. Context for Discussions – Nanosatellites

Nanosatellites were not considered in the 2007 Workshop (they were discussed in a community-wide Workshop in 2004), but are now an interesting option for cost-effective access to space. The rapid advancement of space technology now allows small-satellites to perform missions previously requiring large spacecraft, at a fraction of the cost. Canada is well positioned to capitalize on these new roles for small satellites.

In 1998, Canada began work on the Microvariability and Oscillations of STars (MOST) microsatellite, which was to be Canada's first space telescope. The MOST project marked the beginning of a new era for microsatellites in which these sub-100 kg platforms could perform demanding science missions. In other words, the platform became a tool to accomplish a mission, rather than the mission itself.

The "CubeSat" concept was developed by Prof. Bob Twiggs, Stanford in collaboration with Prof. Jordi-Puig Suari at the California Polytechnic State University in San Luis Obispo (CalPoly) over the period 1999 to 2003. The CubeSat P-POD dispenser could carry up to three 1 kg, 10 cm satellites provided they followed the CubeSat standard. This development provided the opportunity for hands-on satellite engineering educational programs on very limited budgets. However, no launch facilities were available. In 2003, Canada, through the efforts of the Space Flight Laboratory (SFL) at the University of Toronto, arranged and supported the launch of the first CubeSats into space.[3] That day marked two significant events: the promotion of microsatellites to high-performance missions, and the emergence of sub-10kg "nanosatellites" and sub-1 kg picosatellites as vehicles for space education. In both cases, Canada played a key role.

Following the 2003 launch, SFL began working on the CanX-2 nanosatellite (a "triple" CubeSat) and also a new dispenser called the "XPOD" that was flown successfully in October 2005. The wholly Canadian XPOD provides flexibility and lower risk over the American P-POD by virtue of using one dispenser per satellite, instead of loading up to three satellites in one dispenser. Other developments followed in rapid succession:

- By 2008, SFL had arranged the launch of five nanosatellite clusters through its Nanosatellite Launch Service (NLS).

[3] These included SFL's CanX-1 and various other university CubeSats including AAUSat-1 (Denmark),DTUSat-1 (Denmark), and Quakesat (USA). SFL launched two P-PODs carrying these satellites on the same rocket that launched MOST, a Rocket launch vehicle out of Plesetsk, Russia on 30 June 2003

- SFL developed its Generic Nanosatellite Bus (GNB)[4] that supports 7 kg missions in a 20cm cube satellite and does not follow the CubeSat standard.
- In April 2008, SFL successfully launched CanX-2 and CanX-6, also known as Nanosatellite Tracking of Ships (NTS), based on the GNB structure with CanX-2 internals. Both satellites have successfully operated in orbit for approximately two years at the time of writing.
- SFL has also begun work on NEMO-AM, a 14 kg nanosatellite to monitor global aerosols for the government of India.

Canada is now looking to leverage existing technology, capabilities and expertise while building capacity in key areas. The above Canadian accomplishments illustrate two possible opportunities for Canada going forward: (a) educational missions based upon the CubeSat standard, with assistance from the NLS program for launch arrangements, and (b) high-performance missions, or targeted missions for science, Earth observation, communications, etc. that could benefit from the advances in nanosatellite platforms already made by Canada over the last 10 years. Such high performance missions could leverage the capabilities of the GNB (or NEMO bus) while focusing current attention on instruments and mission concepts. In both cases, (a) and (b) there would be great opportunities for the training of highly qualified personnel.

Furthermore, the CSA has developed, internally, two micro/nano satellite demonstration projects – QuickSat and JC2Sat.

While nanosatellites are not strictly sub-orbital platforms, they share a key characteristic: they provide relatively rapid and cost-effective access to space. For educational missions, it is anticipated that the dominant cost will be that of launch, perhaps as little as $100 000 plus launch costs. For targeted, high-performance missions, if existing platform technology is leveraged, these missions could be accomplished within an overall framework of 3 years and $3 million.

The CSA intends to develop a grants and contributions program to support a limited number of nanosatellite missions per year, depending upon demand, complexity and cost. One approach may be to support multiple lower cost educational missions, and a limited number of higher-performance missions requiring larger project budgets.

A survey of space activities around the world provides some key characteristics of nanosatellite missions.

	Key characteristics	
Parameter	***CubeSat missions***	***Targeted nanosatellite missions***
Satellite Mass	< 3 kg	7 - 14 kg
Mission Life	6 months nominal	1 year nominal
Average Power	2 - 6 W	5 - 20W
Orbit	400 to 800 km altitude (low Earth orbit)	400 to 800 km altitude (low Earth orbit)
Launcher	Ariane, Dnepr, PSLV, H2A	Ariane, Dnepr, PSLV, H2A
Attitude Control	No attitude control, or passive	Spin-stabilized, 3-axis stabilized,

[4] In support of the BRITE (CanX-3) space astronomy mission, the CanX-4&5 formation flying mission, and the AISSat-1 maritime monitoring mission for Norway.

Mode	attitude control through gravity gradient or magnetic systems	gravity gradient stabilized, momentum bias control, 3-axis control, passive or active magnetic control
Propulsion	Limited cold gas	Butane, SF6
Communications	UHF, VHF	UHF, VHF, S-band

In addition to research using nanosatellites, the new CSA program proposes to provide funding for the further development of satellite technologies and how these technologies can be incorporated into future space missions.

Some areas, both scientific and strategic, that can be probed using nanosatellites include: astronomy, solar-terrestrial physics, atmospheric science, aeronomy, earth observation, geophysics and communications.

Major outcomes of the 2004 workshop

- Although some professors have positive experience with current CSA programs, others feel there is room for improvement. This is particularly true for young and new professors who usually don't have a lot of contacts with industries.
- Not only both space science and space technology development at universities require higher levels of CSA support, the support should be synchronous with the academic programs. Also, the CSA should support both innovation and education, which are long-term process. As such, a program that will have multi-year support element is highly recommended.
- The CSA should provide long-term strategy and road-map for science and technology development to the universities.
- The opportunities available to the universities are limited. Improving communications and seeking flexibility in the programs would be the key.

3. Context for Discussions – Balloon Platforms

This breakout session provides the opportunity for potential users of balloon platforms to shape an action plan for the development of a forward program and the necessary infrastructure. Foremost among the priorities is for the research community to identify how best to develop a proposal (or proposals) for a Canadian-based and academically managed balloon launch facility that could be submitted to CFI and partnered by the CSA. See also below for the recommendations emanating from the 2007 Workshop on which this discussion builds.

The CSA has identified astronomy, atmospheric and space studies using balloon-borne payloads as a prime vehicle to support training the next generation of scientists and engineers as well as providing support for research and the testing of high-risk payloads for other missions.

The Workshop break out group should also advise the CSA on the following items:

- The extent to which long-duration flights will be a research priority. This could include trans-Atlantic flights (Europe to Canada) and circumpolar missions that would require agreements with Russia to allow over-flights of Russian territory
- How data will/should be managed – e.g. data repositories, archiving and accessibility regimes. [5]

Examples of atmospheric research questions of interest to Canadian scientists that can be (or are being) addressed from a balloon platform – from 2007 Workshop

- 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.)

Examples of astrophysics research questions of interest to Canadian scientists that can be (or are being) addressed from a balloon platform – from 2007 Workshop

- 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?

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[5] For example – see http://www.wdc.rl.ac.uk/wdcmain/europe/ratmosphere.html; http://www.wdc.rl.ac.uk/wdcmain/usa/atmosgas.html

- When did the first stars form?
- Where did the initial matter density fluctuations come from?
- Why is the universe so smooth?

Balloon Recommendations - from 2007 Workshop[6]

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 the 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.[7]
12. The Canadian ballooning community should reconvene to make a coherent plan with firm recommendations regarding the future of Canadian launch capabilities.

4. Context for Discussions - Aircraft

This breakout session provides the opportunity for potential users of aircraft to provide input to the CSA on an action plan, in the context of CSA's future plans in the areas of Capacity Building and mission support. See below for the recommendations emanating from the 2007 Workshop on which this discussion builds.

[6] These recommendations extracted from the Final report of the Community Workshop on Science from Suborbital Vehicles, February 1&2, 2007
[7] Now closed down by Environment Canada

The Workshop participants should identify priorities for infrastructure enhancement and for access. The Workshop breakout group should also advise CSA on how data will/should be managed – e.g. data repositories, archiving and accessibility regimes. [8]

Aircraft parabolic flights offer user the following benefits:

- Depending on the aircraft up to 20 seconds of weightlessness – usually with levels of $\leq 10^{-2}$g
- Low cost and very flexible approach, especially valuable for research training and for preparing for longer missions.
- Use of relatively standard instrumentation
- Value for research involving human subjects under conditions of weightlessness
- The possibility of direct intervention in the experiments during the flight by the research team, and easy access to modify the experimental set up between flights.

Aircraft flights for earth observation, both those that are dedicated to the lower to mid troposphere (< 8 km) and those that deal with the upper troposphere to lower stratosphere (8 to 20 km) offer users the following benefits:

- Experimental access to the troposphere and lower stratosphere region
- Relatively low cost and very flexible approach, especially valuable for research training
- Low cost and very flexible approach, especially valuable for research training
- Use of relatively standard instrumentation and allows for the presence of an operator
- Good platform for the testing and validation of instruments to be flown on other missions
- The possibility of direct intervention in experiments during the flight by the research team, and easy access to modify the experimental set up between flights.

For the Space Life and Physical Science community there is interest in using aircraft to conduct research on reduced gravity research; e.g., the use of parabolic flights.

Parabolic flight achieves periods of reduced gravity, usually ranging from 8 to 20 seconds. This is done by flying aircraft in a steep climb, from ~10 000 ft to ~20 000 ft. Near the top of this climb, the aircraft's thrust is adjusted so that the aircraft and its contents are not experiencing lift. Thus, the aircraft is in freefall, and the gravitational force decreases to ~0.02 g as the aircraft reaches the peak of the parabola and begins to descend. This period of microgravity ends when the pilot increases the thrust to pull out of the descent. When the aircraft has descended to about 10 000 ft, the plane levels off, the equipment is readied for another experiment, and the aircraft begins another ascent. During the leveling off (pull out) and the beginning of the ascent (pull-up) period, the aircraft experiences ~1.8 g.

Canadian parabolic flights offer the following benefits:

- In each flight, the cycle is repeated approximately 10 times. This allows flexibility in experimental design, since there is more than one period of reduced gravity.
- aircraft usually can accommodate powered equipment,
- a number of people can participate in running the experiments.

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[8] For example – see http://www.wdc.rl.ac.uk/wdcmain/europe/ratmosphere.html; http://www.wdc.rl.ac.uk/wdcmain/usa/atmosgas.html

Unfortunately, there are several drawbacks to parabolic flight. The recurring cycle of hypergravity may make experimental interpretation difficult, depending on the experimental design. Also, the short period of reduced gravity restricts the type of experimentation that is possible.

Research questions of interest to Canadian scientists that could be addressed using the NRC-managed aircraft platforms – extracts from 2007 Workshop

Note – users of parabolic flights did not participate in the 2007 Workshop.

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.

The NRC has two aircraft that can operate in the UTLS region. 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[9] 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.

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[9] These flights did not occur

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*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[10] 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…. It is expected that the NRC CT-33 and Falcon[11] will be used for validating instruments remote sensing of the UTLS region from orbit.

Aircraft Recommendations - from 2007 Workshop

- Include aircraft as platforms within the scope of the Small Payloads Program.
- 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.
- 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.

[10] This did not occur
[11] The Falcon flights did not occur.

D ATTENDANCE DETAILS

D.1 TOTAL REGISTRATION

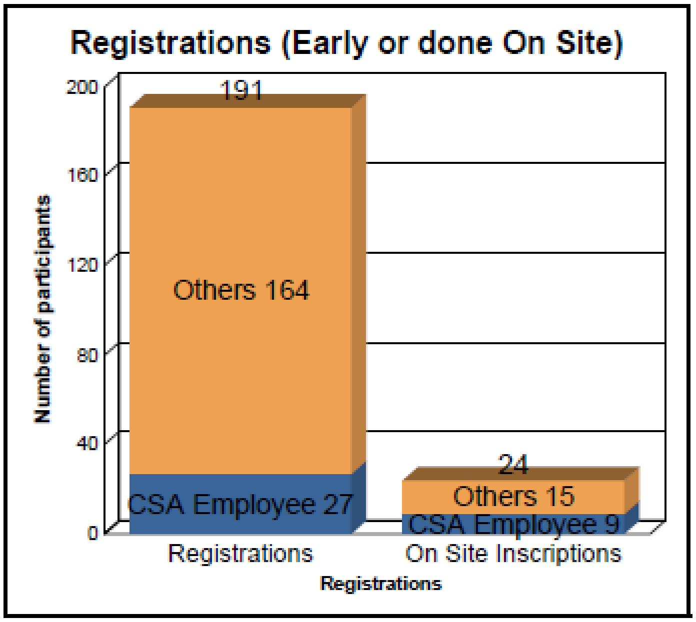

FIGURE D-1 – TOTAL REGISTRATION

D.2 THEME INTEREST OVERVIEW

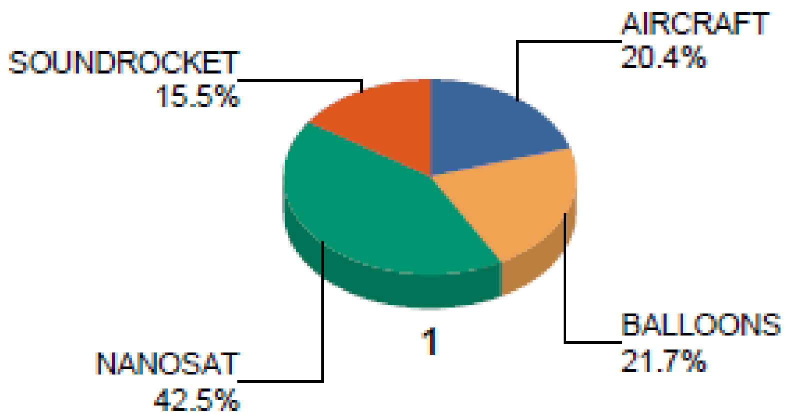

FIGURE D-2 – REGISTRATION PER THEME INTEREST

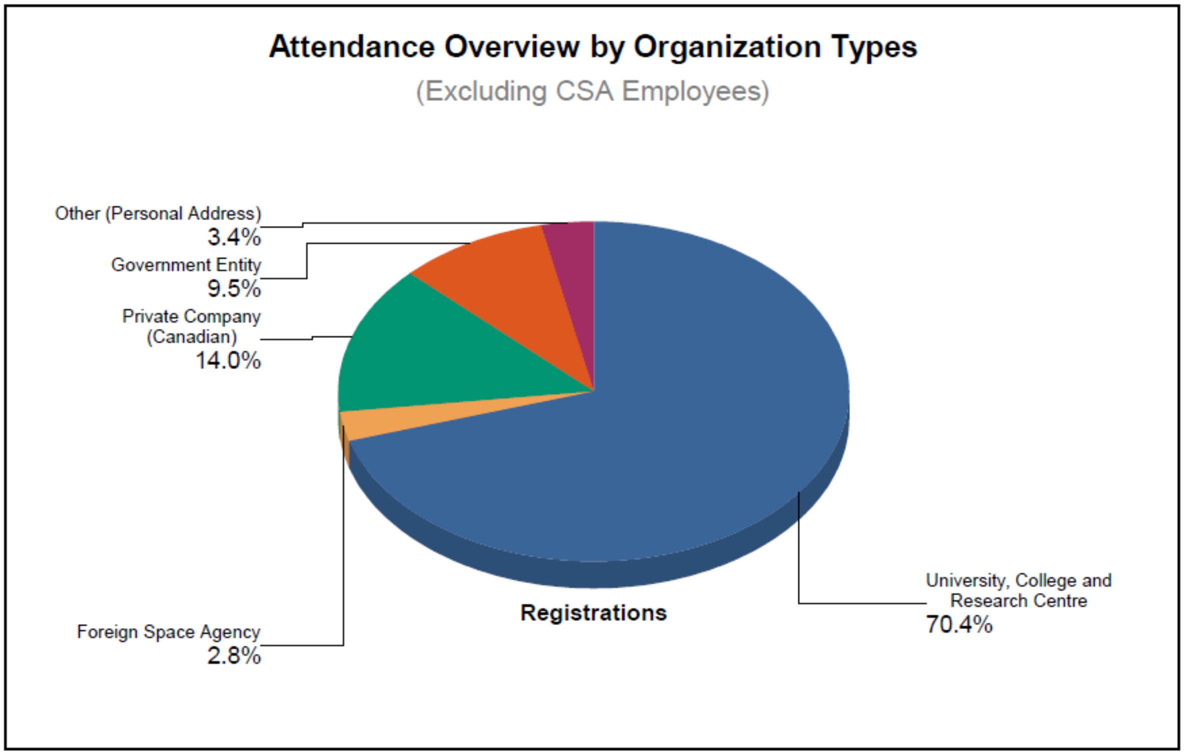

FIGURE D-3 – ATTENDANCE BY ORGANIZATION TYPES

E LIST OF ALL RECOMMENDATIONS IN THE FINAL REPORT

E.1 AIRCRAFT SESSION

E.1.1 Parabolic Flights Research

1) CSA should structure and schedule all future AOs to ensure stability of funding, guaranteeing continuity of graduate student and post-doc support, for research programs that continue to meet objectives and win approval in a peer-review process.
2) The funding level per project should be increased sufficiently (even at the expense of funding fewer projects) to enable adequate personnel for graduate student and post-doc specialization (hardware development, data analysis, modeling, etc.), permitting a greater scientific return on program investment.
3) Funding should be integrated into identifying and developing scientific investigations that have evolved to required longer-duration platforms (the ISS, in particular). Commitment is required to develop the hardware necessary to transfer investigations originating from parabolic flight research to other platforms (sounding rocket, ISS, etc.).
4) The Falcon-20 operating out of the NRC Flight Research Laboratory should continue to be supported as the primary national platform for parabolic flight research. While the capacity of the recently upgraded aircraft is sufficient for current and anticipated research needs, further investment into ground-based facilities for better on-site payload integration and access to off-site facilities for post-flight analysis of samples would increase the results generated by flight campaigns.
5) Over the next decade, the eventual replacement of the Falcon-20 with a pre-existing, Canadian-built platform should be explored. The use of a Canadian-built aircraft would present a substantial public relations opportunity.
6) The Canadian reduced-gravity research program should continue to build upon collaboration with other international programs via utilization of their reduced gravity platforms and the ESA Airbus A300B in particular. The Canadian Falcon-20 and the European Airbus A300B are seen as filling highly complementary roles.
7) The G&C program and Research Chairs should be used to promote renewal for a new generation of academic researchers that utilize reduced gravity for physical science research. The current generation of researchers in this field is maturing, and the Research Chairs program could be a means of attracting talent of international standing to Canada.

E.1.2 Earth Observation Research Aircraft

1) CSA should structure AOs that:
   a. Call for multi-disciplinary aircraft studies in support of major missions of interest to CSA.
   b. Provide funding for aircraft flight hours, and integration and access costs for existing or new equipment and for the training of HQP
2) CSA should coordinate its G&C program with other university funding agencies to improve university access to earth observation funding through:
   a. Presenting the case for an extension of the NSERC Ship Time Program to aircraft work
   b. The provision of CSA funds to enhance CFI grants
3) There should be promotion of the use of low cost aircraft to facilitate entry level or more simple projects by this community, where requirements do not dictate sophistication of NRC aircraft.
4) CSA should enhance its support for NRC, CCRS and EC facility usage to maintain necessary engineering readiness to better serve the university community. A Memorandum of Agreement (MOA) with a discretionary framework between CSA and Other Government Departments (OGD) to support this type of activity should be pursued. An example of this approach is the existing Memorandum of Understanding (MOU) between EC and NRC for collaboration on aircraft programs, and the NRC-CSA MOU for parabolic flight.
5) CSA should commission a white paper from the earth observation community that further documents existing aircraft capabilities within relevant government agencies (NRC, EC, CCRS), university interest in earth observation studies using aircraft and future directions of research using aircraft capabilities for earth observation within Canada.

E.2 BALLOON SESSION

The discussions led to the following recommendations:

1) The highest priority of CSA should be the development of an adequate program to fund scientific ballooning projects, including science studies, instrument and flight systems development, and data exploitation. The development of HQP is mainly through these projects. Due to the diversity of the ballooning community, the program should be flexible with respect to the needs of different project models and collaborations. Funding of infrastructure should not be at the expense of funding scientific balloon projects.
2) A mechanism for funding Canadian launches of small payloads (<70 kg) should be developed to provide launches in coordination with the flight needs and funding opportunities for these payloads. Canadian suppliers can meet the projected needs for these flights over the next decade.
3) An agreement between CSA and NASA-CSBF to launch large (>1 tonne) Canadian payloads should be pursued in coordination with the flight needs and funding opportunities for these payloads.

4) In order for the development of a mobile Canadian launch facility for medium sized (> 70 kg and < 1 tonne) payloads to be pursued, the following conditions should first be met:
    a. There must be a vibrant program functioning and funding the scientific balloon projects which are to be flown.
    b. For long term stability, the funding of the launch capability must be based on its own program, rather than being tied to funding decisions of individual projects.
    c. CSA must actively pursue international partners and users for this facility for long-term sustainability.
5) The development, with active community involvement, of generic flight systems including pointing control for science instruments should be explored. The active community engagement is crucial to ensure that the systems will meet the needs of actual (current or future) funded projects.
6) Funding opportunities for community building should be provided, including meetings to share expertise, raising the profile of balloon opportunities, and support of outreach and undergraduate research opportunities (such as support for students to participate in the BEXUS program).

With the support of the community, the session chairs, Kaley Walker and Barth Netterfield, have agreed to act as community point of contacts for the development of the ballooning program.

E.3 SOUNDING ROCKET SESSION

The top priority is to get flying again, and to stay flying. We therefore recommend that CSA

1) Maintain and enhance Canada's ability to participate in international collaborations by
    a. Ensuring sufficiently frequent and regular AOs
    b. Put in place a flexible, open and timely mechanism to allow Canadian scientists to respond to international flights of opportunity
2) Participate in a scientific rocket mission at least every year combining Canadian and foreign led missions.
3) Work to increase the number of Canadian groups involved in rocket research by encouraging and enhancing student recruitment and outreach
4) CSA should provide funds, through one of its new programs, to support Canadian students participating in student rocket and science programs in Canada and internationally, such as
    a. CaNoRock, REXUS, and similar programs
    b. "Design and build" competitions
    c. Summer schools
5) Encourage rocket-borne testing of instruments destined for orbital missions but having no previous flight heritage (risk mitigation)

In addition, the government, academia and industry should work together to

6) Follow through on development of lower cost rocket platforms (e,g., Excalibur) and CRV-7 launcher capability
7) Provide a mechanism for stable employment for highly qualified personnel, including:
    a. Engineers, technicians and scientists in universities and industry
8) Develop university laboratory facilities and courses (senior level design projects, lab work, capstone, competitions)

E.4 NANOSATELLITE SESSION

1) Canada already has existing infrastructure in nanosatellites that is internationally recognized. Several nations are already taking advantage of Canadian nanosat technology and expertise at UTIAS/SFL – Canada should do the same and exploit SFL nanosat technology and expertise for targeted science and technology missions.
2) Support the MSTC that has already been mandated with championing new initiatives by establishing synergies with the CFI-funded MSTC to develop technologies, payloads, instruments and mission concepts in collaboration with established university groups (Calgary, York, Lethbridge, New Brunswick, Toronto, etc). Utilize SFL's very active Nanosat Launch Service.
3) CSA should proceed with its program in suborbital & Nanosatellites to provide ideal opportunity to fund initiatives championed by the MSTC.
4) Research Infrastructure Program (RIP) – CSA should direct new infrastructure funding to complementary facilities and sustain existing centre of excellence through the new RIP presented at the workshop
5) FAST – CSA should proceed with the new program FAST which can help fund new, fast missions, but new ideas are needed:
    a. BRITE
    b. Nano-TICFIRE
    c. "PROBA" like autonomy experiments on a nanosat
    d. GPS radio occultation – global mapping of atmospheric properties
    e. Tethered nanosatellite, electrodynamic tether