On-Orbit Experience and Lessons Learned in Canadian CubeSat Project (CCP)

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ABSTRACT

CCP was initiated in 2017 by the Canadian Space Agency. 15 CubeSat proposals submitted by Principal Investigators (PI) were selected and funded. The PI created students in the design, manufacture, test and operate of the CubeSat. CCP involved students from all Canadian provinces and territories. This paper discusses the strategies taken to support the students throughout the project. 14 out of 15 missions were eventually launched to ISS and released into orbit. The 15 missions consist a wide range of mission objectives. This paper highlights three of them which carry payloads in space radiation, space weathering and astronomy. The on-orbit experience of the CCP missions is discussed. Finally, key lessons extracted from CCP are highlighted.

1. INTRODUCTION

The Canadian Space Agency (CSA) launched a Canadian CubeSat Project (CCP) Announcement Opportunity (AO) in November 2017. The primary objective is to train next generation Highly Qualified Personnel (HQP) in the space sector. The AO provide students in colleges and universities in Canada an opportunity to design, build, test and operate a CubeSat. Each selected team receives a grant about €150,000 for material, equipment, and salary. The launch was paid and arranged by the CSA. The secondary goal is to have student participation from all 10 provinces and 3 territories. Considering that space science or engineering is not available in the undergraduate curriculum in 4 provinces and 3 territories, it was uncertain whether any proposal would have been submitted by any university or college from those provinces and territories. Nevertheless, a budget for 13 CubeSat missions was set aside. At the closing of the AO, 19 proposals were received and unexpectedly there was indeed at least 1 proposal from each province. Two out of three territories also submitted a proposal while the third territory participated as a partner in one of the proposals. The two most populous provinces of Canada, Ontario and Quebec, had 6 institutes submitting proposals. The response indicated clearly that the interest in space exists in every region and province of the country. After an internal evaluation process and obtaining extra funding, the CSA management agreed to fund two runner-up proposals from Ontario and Quebec. At the end, 15 proposals were retained and the secondary goal of CCP was fulfilled.

2. PROJECT KICK-OFF

The CCP AO accepted proposals of 1U, 2U or 3U formats. The distribution of form factors in the proposals and the final selection is shown in **Table *1***.

Table 1 Distribution of CubeSat Form Factors in CCP AO

Form Factor	Proposal	Final Selection
1U	1	0
2U	14	11
3U	4	4

The fist task in the implementation is the selection of launch provider. The ISS orbit was quickly decided

a. Delivering a payload to a human space flight has more stringent safety requirements. All these will increase the learning experience for students.
b. The operation altitude of ISS (between 350 and 400 km) ensures that CubeSat launched will be de-orbited in a timely fashion.

A contract was put in place with Nanoracks for 34U delivery service. As it was expected that not all teams would have completed the CubeSat at the same time, a provision was added in the contract that would allow the CubeSat to be delivered in up to 3 batches with no restriction on the size of each batch.

The Kick-off Meeting with all the teams was held virtually in June 2018. CSA emphasized three points to all teams:

a. The competition was in the application stage and there should not be any competition in the development stage. From that point on, collaboration among the teams was strongly encouraged.
b. Teams were told not to under-estimate the effort required to make the subsystem. Time and effort required could far exceed the cost saving of making the subsystem.
c. For commercial off the shelf (COTS) components, teams should explore the feasibility of group buys among them.
d. To give the students the experience of a space mission, CSA would manage CCP as a space project with four major milestones: Mission Concept Review (MCR), PDR, CDR and FRR.

The milestone approach also has another advantage. All payloads transported to the ISS are required to submit Safety Data Package (SDP) and Bill of Materials (BOM) to NASA ISS Payload Safety Review Board three times. For CCP, the teams were requested to deliver SDP and BOM at PDR, CDR and FRR milestones.

Prior to CCP, the closest space experience the Canadian students had was gained through the Canadian Satellite Design Challenge (CSDC) organized by a non-profit organization. The CSDC was held once every two years and it attracted about 10 teams from a handful of provinces across Canada. In this challenge, each team of students was asked to build a 3U CubeSat engineering model with a functional payload. The finale of the competition is a vibration test campaign for the completed CubeSat. The winner is determined by a panel of judges giving scores based on the CubeSat design and vibration test results. The CSDC experience indicated that the space knowledge base was limited to engineering model level. The base was also scattered and concentrated in a handful of provinces only. In developing the CCP AO, CSA has identified this to be a key issue for the success of the project. In following government directives in managing grants, CSA must maintain an arms length relationship with grant recipients. In other words, CCP grant recipients were not expected to receive any non-financial assistance from CSA. A special permission was requested and eventually approved that allowed CSA in house experts to provide technical assistance to CCP teams on two conditions:

a. Provide the assistance in an open and transparent fashion to all teams.
b. Avoid any support that can lead to a perception of favoring one team over others.

It should be pointed out that there was limited availability of internal expertise to provide mentorship to the teams. Besides having the teams spread over 6 time zones posed a scheduling challenge. CSA technical team proposed to the senior management that the success criteria of CCP should be limited to the CubeSat being accepted to launch by NASA PSRB. With this criterion, the technical team focused on the CubeSat bus and payload design, build and tests. The data quality of the payload design was not in the scope of the mentorship. After the 15 teams were selected, CSA identified 9 teams had no prior experience with satellite or any space project. If no support was provided immediately, there was genuine concern that these teams could be discouraged and abandon the project quickly. Transferring knowledge to the teams became the top priority. At the KOM in June 2018, CSA recommended a schedule (Figure 1) to the teams which could see the delivery of the first CubeSat within 3 years.

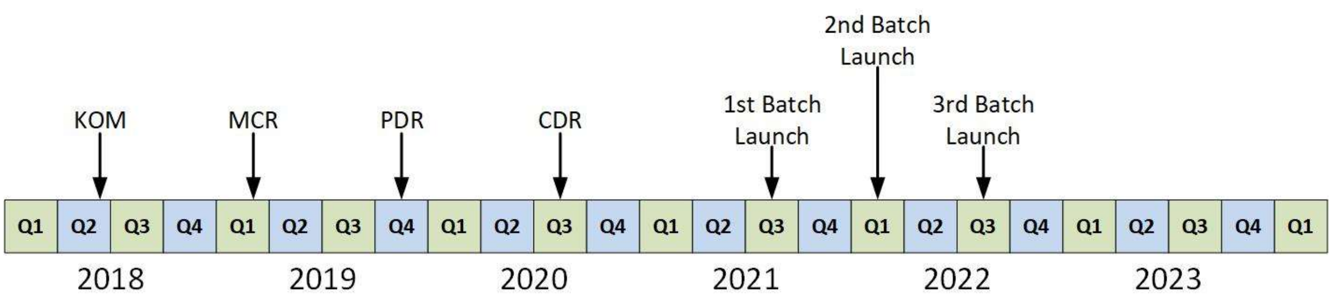

Figure 1 Proposed CCP Schedule at KOM

This schedule provided 6 months for Phase A, 9 months for Phase B and Phase C. Phase D was estimated to be 12 months. Considering this was the first attempt by Canadian universities building flight ready CubeSat, this schedule was deemed to be reasonable. Nevertheless, this schedule assumed the teams had the necessary knowledge which was obviously not the case. As such, CSA also announced at KOM that a series of webinars on spacecraft engineering (e.g., power subsystem, RF communications, structures) were prepared and would be offered by CSA experts within 3 months. Using webinar format also conformed with the approved condition for mentorship.

3. MISSION CONCEPT REVIEW (MCR)

Six months after the KOM, the MCR was held with all the teams. To encourage information exchange among teams and to minimize the travel cost for the teams, 3 separate group MCR were organized – Western (6 teams), Central (4 teams) and Eastern Canada (5 teams). Not only the MCR provided the first face-to-face meeting with all the teams, the MCR provided opportunities of in-depth discussion with all the teams and allowed CSA to assess the strength, weakness and potential challenges facing each team. Three key lessons learned from the MCR:

a. The webinars on spacecraft engineering definitely provided good foundation to all teams especially the novice teams. However, CSA team found there were still knowledge gaps that could not be taught through webinars.
b. Since Systems Engineering was not in the engineering curriculum, its importance was overlooked or was not implemented properly by most of the novice teams.
c. Spectrum licensing and ground segment design needed a momentum push.

At the conclusion of the MCR, CSA technical team understood that the mentorship planning needed significant improvement. Two new initiatives were quickly added to increase the mentorship offering: internship and CubeSat Workshop. Several internship opportunities were posted in the universities. Students who were a member of a CCP team were given priority. Having the students working alongside experienced engineers inside CSA, these students could gain practical spacecraft building knowledge especially systems engineering in a short time. Once the internship was over, their experience could benefit their teams. This internship strategy worked out very well as 3 novice teams showed marked improvement by PDR.

4. CUBESAT WORKSHOP

Through the discussions at MCR, it became obvious that the majority of CCP teams were lacking basic hands-on experience in the electronics assembly including safe handling of electronics. Transferring this know-how could not be done efficiently through virtual means. A 5-day CubeSat Workshop was organized in May 2019 and 3 students from each team were invited to participate at CSA HQ. During the week, a series of seminars and hands-on workshops were offered. Key experience gained for the students: safe handling of flight electronics, basics in soldering, building flight harness, conducting vibration tests and interpretation of test data (Figure 2), etc.

Figure 2 Workshop on soldering (left) and demonstration of vibration test (right)

5. PDR

Three regional PDR were held in October 2019. Compared to MCR, there was marked improvement in all teams, especially the novice teams. The materials were presented logically and systematically. Among the 15 teams, there were still some variations in the maturity of their CubeSat designs, but the majority met the PDR requirements. Some teams actually provided detailed designs in most the subsystems that they were close to CDR level readiness. Feedback from the students demonstrated the internship at CSA and the CubeSat Workshop did make a measurable impact on the teams. Indication of team collaboration was also observed and proved to be beneficial.

Shortly after the PDR, Nanoracks assisted the teams in submitting the BOM and SDP to the NASA PSRB for the first Safety Review. All teams passed with only minor issues that could be addressed in future Safety Reviews. At that moment, CSA had great confidence that CCP was on track for first batch delivery in 2021.

6. COVID & CDR

World Health Organization declared on March 11, 2020 that COVID-19 as a worldwide pandemic. Canadian government immediately rolled out sanitary measures across the country such as work from home order until further notice. Universities across Canada started to move classes to online and laboratories started to close or access with restrictions. Each province implemented its own sanitary measures to universities. The majority chose a complete shutdown approach while the minority adopted a restricted access approach. Among the 15 CCP teams, less than 5 could maintain access to their laboratories with 1 or 2 students. The other teams had the access completely cut off. With the academic year coming to an end in April, all teams did not have a chance to do an in-person transition of knowledge and responsibilities from graduating students to their successors in the project. This is particularly critical in transferring the responsibilities of laboratory equipment, breadboard under development or testing.

The CDR was originally planned for the fall 2020. When the shutdown COVID-19 did not seem to disappear anytime soon, it was decided to stick to the original schedule for the next design review. It was anticipated that most teams would not be able to advance the maturity of the CubeSat design to CDR expectation. As such, each team presented whatever they had achieved. For subsystems that did not meet the CDR requirements, each team was offered a delta-CDR opportunity.

By Q2 2021, all teams completed the CDR requirements and the second Safety Review. However, that already represented a year delay in the project. All teams regained access to their laboratories with limited capacity. Phase D work started for all teams with a lower number of students in order to be compliant with social distancing rules which remained effective until end 2021. Many AIT work needed to be carried out in sequence instead of in parallel. For example, while the electrical engineers were working on the power subsystems, mechanical engineers could not work in the same laboratory on the CubeSat structure. Furthermore, supply chain issues, particularly in the electronic parts, led to parts shortage creating an impact on the delivery of some subsystems. All of this added a further schedule delay to the project.

7. FRR AND CUBESAT DELIVERY

The severity of COVID impact was uneven across all 15 teams. Generally speaking, teams that had a larger number of student participation weathered the pandemic better. In other words, teams of smaller size tended to make much less progress compared with teams of larger size. By Q3 2021, it became obvious that the CubeSat would require three batch delivery schedules, with the vast majority in the final batch. The first batch of two CubeSat was finally delivered to Nanoracks in October 2022 and launched to ISS in November 2022. A month later, they were deployed into orbit. The second batch of four CubeSat was launched into orbit in April 2023 while the third batch of five CubeSat was inserted into orbit three months later.

After the delivery of second batch CubeSat, there were nine teams left. Seven teams looked were committed to be ready for the final batch delivery while two teams had indicated that they were ready to abandon. The focus was then turned to assist the seven teams in the final dash towards the finish line. CSA held weekly meetings with teams to gauge the progress and to provide support whenever and wherever needed. The progress was promising until a few days before the CubeSat integration. Two teams encountered unrecoverable technical issues.

The delivery of the third batch should have been the end of the contract between CSA and Nanoracks. Both parties looked at the remaining four teams with regret especially the two that came so close to the finish line. The technical team decided to approach the remaining four teams. Other than one team, the other three teams remained interest to have their CubeSat launched. After more discussions with CSA senior management and with Nanoracks, CSA agreed to provide a contract amendment for the fourth batch launch and the teams were given 6 more months to complete their AIT. They were delivered to Nanoracks in November 2023 and were launched to ISS on March 21, 2024. The CubeSat were inserted into orbit on April 18, 2024 and that marked the official end of CCP. The complete schedule of the CCP is illustrated in Figure 3 where the number in brackets indicates the number of CubeSat in each launch.

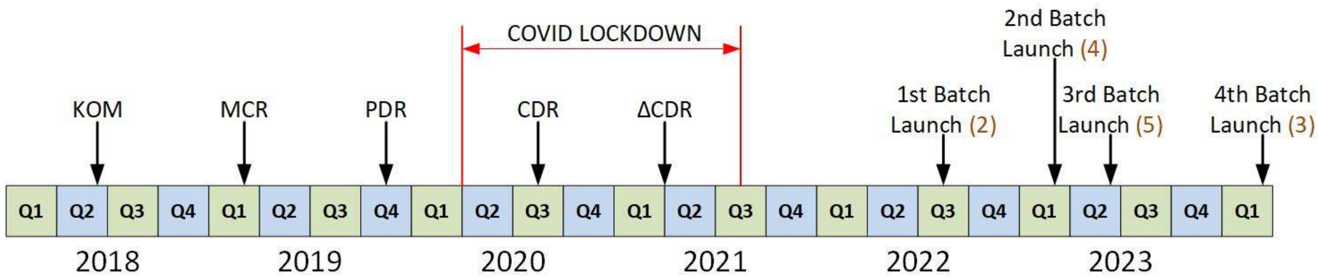

Figure 3 CCP Final Milestone and Delivery Schedule

In the following sections, three CubeSat missions are presented. They are chosen among the 15 CubeSat missions to illustrate the uniqueness of these payload concepts.

8. MISSION EXAMPLE: NEUDOSE

The NEUtron DOSimetry & Exploration (NEUDOSE) CubeSat is a 2U CubeSat developed at McMaster University (Figure 4). NEUDOSE aimed to advances the technology readiness level (TRL) of the Charged & Neutral Particle Tissue Equivalent Proportional Counter (CNP-TEPC) instrument. It took up 1U of volume, potentially fitting on an extravehicular backpack of astronauts during space walks. The CNP-TEPC has the potential to revolutionize the way radiation risk is characterized by enabling detailed measurement of the actual radiation field incident on each crew member on a particle-by-particle basis in real-time, a capability that has never before been achieved.

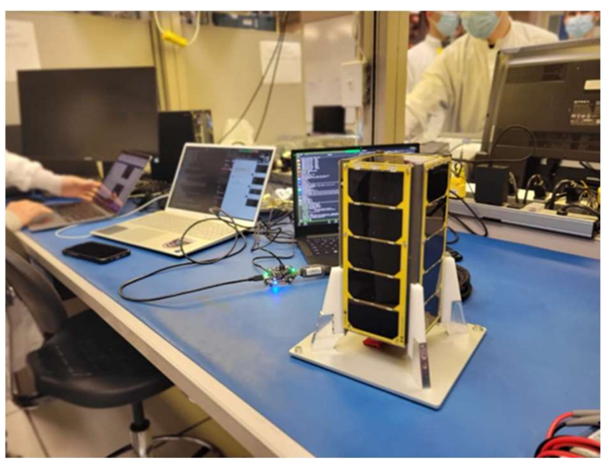

Figure 4 Photo of the NEUDOSE 2U CubeSat prior to integration into the Nanoracks deployer at the CSA headquarters

The CNP-TEPC instrument (Figure 5) consists of two detector technologies that have been seamlessly combined to enable real-time discrimination of absorbed dose and quality factors from charged particles and neutrons. The first technology is a spherical Tissue Equivalent Proportional Counter (TEPC) that is fabricated using the most recent techniques developed by NASA. Made from A-150 plastic, which is both electrically conductive and tissue-equivalent, the spherical TEPC is mounted inside a lightweight pressure vessel and pressurized to approximately 20 Torr with propane gas. The A-150 plastic, which is maintained at ground potential, surrounds a 50 μm diameter gold anode wire that runs through the center of the TEPC sphere and is biased to +800 V. This applied high voltage creates an electric field between the TEPC sphere and the anode wire, allowing for the collection of ionization charge that is generated as radiation events pass through the sensitive volume filled with propane gas. The spherical TEPC, which has an isotropic response, records the lineal energy distribution of incident radiation used for absorbed dose and mean quality factor estimation. However, since the TEPC is sensitive to all ionizing radiation, the measured lineal energy distribution consists of a mixture of charged particle and neutron interactions which are difficult to separate. To separate the neutron component of lineal energy from that produced by charged particles, the CNP-TEPC instrument features an anti-coincidence detector (ACD) that surrounds the spherical TEPC and provides trigger signals whenever charged particles traverse it. This technique capitalizes on the necessity for all charged particles traversing the spherical TEPC detector to also traverse the ACD. On the other hand, neutrons or other neutral particles will deposit their energy in either the TEPC or the ACD, but typically not both.

Figure 5 (Left) McMaster student, Connor Chandran, assembling and staking the vibrational support mount to guarantee the TEPC instrument's resilience during its journey to space (Top Right) The CNP-TEPC instrument, successfully built and deployed aboard the NEUDOSE CubeSat in March 2023 (Bottom Right) Photograph of the dedicated team that was responsible for designing, fabricating, and testing the CNP-TEPC instrument for the NEUDOSE mission

9. MISSION EXAMPLE: IRIS

The IRIS mission was a 3U CubeSat built by University of Manitoba. The mission objective is to determine whether space weathering is geology-dependent and is visually detectable on short time scales. The payload is a tray of 24 carefully chosen geological samples directly exposed to deep space while in orbit (Figure 6). The samples were made into sintered pellets and underwent vibration test to ensure the samples did not crack or disintegrate. Two cameras above measured changes in the visual and spectral properties of the geological samples. In the middle of the sample tray is a gnomon which was co-designed by high school students with IRIS team students. The high school students developed algorithm to determine the sun angle based on the length of the shadow casted by the gnomon.

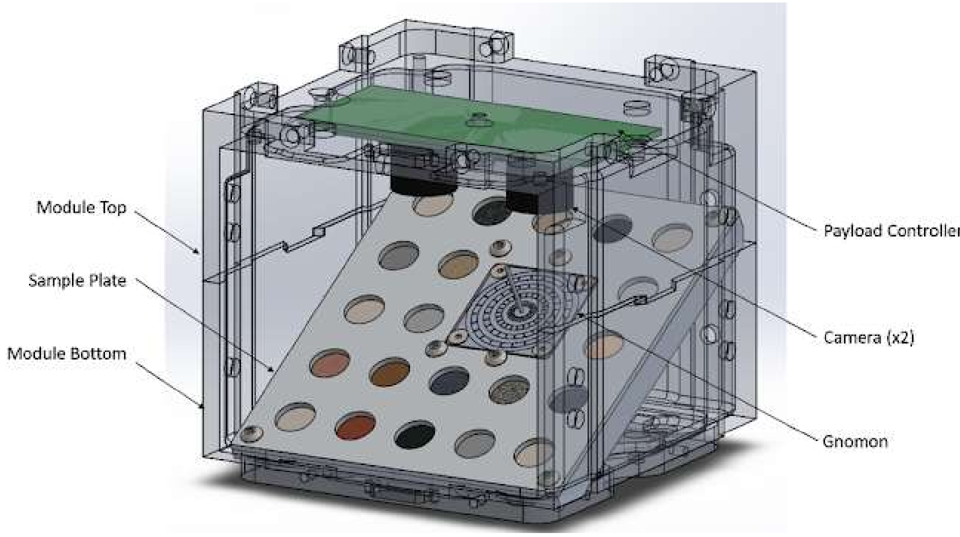

Figure 6 IRIS Payload Tray Layout

The left photo in Figure 7 is the flight model of IRIS taken during AIT. The payload tray is installed in the open cavity in the top half of the CubeSat bus. The top right photo illustrates students working on the integration when sanitary measures remained in place. The middle right photo was taken right after successful integration of IRIS into Nanoracks CubeSat deployer at CSA headquarters. The bottom right photo is the CRS-28 launch which carried the IRIS and 4 other CCP missions to ISS.

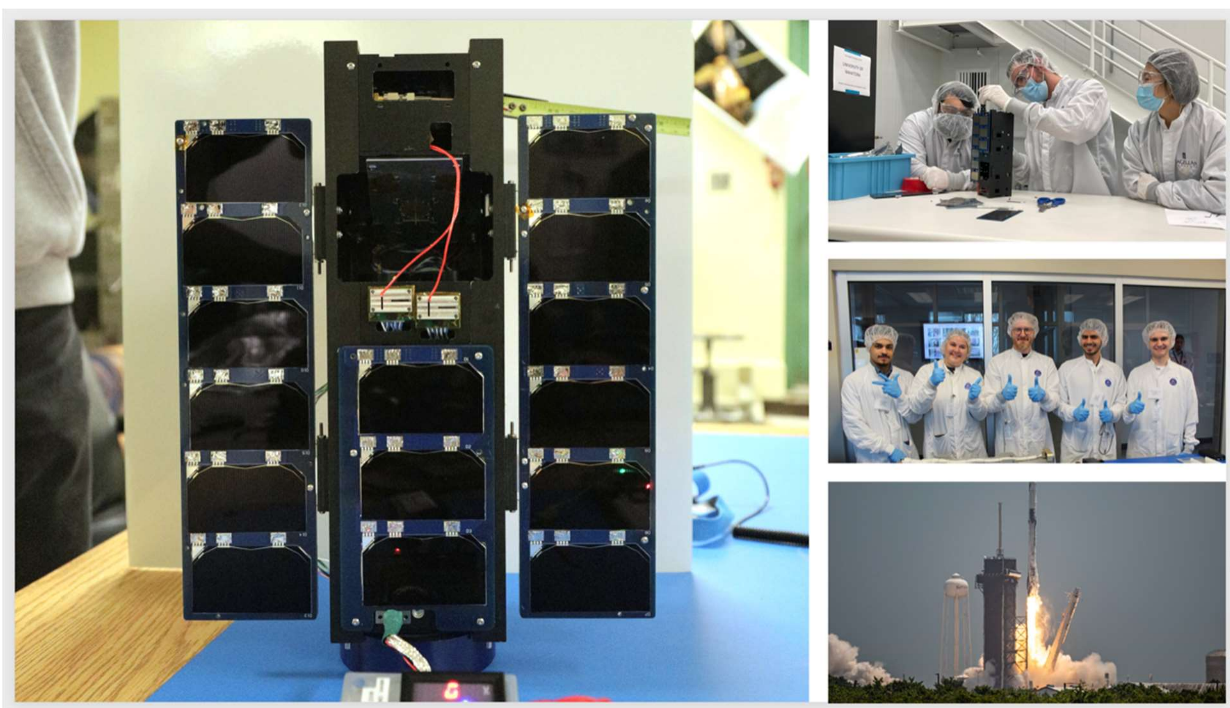

Figure 7 Composite photo of IRIS mission

10. MISSION EXAMPLE: ORCASAT

The Optical Reference and Calibration Satellite (ORCASat), shown in Figure 8, was a 2U CubeSat mission that was developed by the University of Victoria Centre for Aerospace Research (CfAR) and University of Victoria Satellite Design (UVSD) with the help of volunteer students from the University of British Columbia (UBC) and Simon Fraser University (SFU), as a submission to the Canadian CubeSat Project. The mission of ORCASat was highly qualified personnel (HQP) training in space science and technology, using a technology demonstration project for calibrating Earth based telescopes via providing a reference light source in orbit as the framework.

Figure 8 The flight model of the ORCASat spacecraft [A. Doknjas /CfAR]

The ORCASat payload, which realized the above-mentioned reference light source, was developed in collaboration with the UVic Department of Physics and Astronomy. Using a similar light source developed for and flown aboard high-altitude balloons as the starting point, a custom payload of 1U volume was developed, incorporating a light source, diffuser, and calibrated light intensity measurement equipment, illustrated in Figure 9.

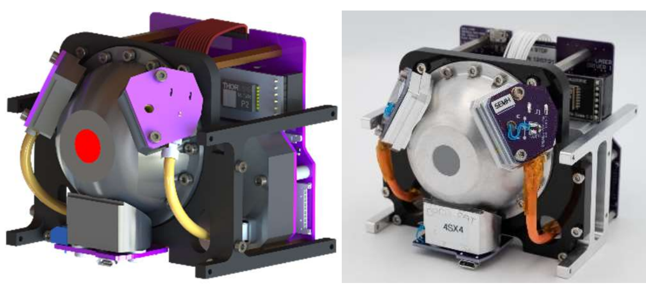

Figure 9 The ORCASat payload module render(left) and flight model (right) [T.Tarnowski & A. Doknjas /CfAR]

To support the operation of the payload, a custom, modular satellite bus was also developed by the student team, illustrated in Figure 10. This was developed from scratch, except for the ADCS subsystem, which was procured from CubeSpace. This, while initially presented a significant learning curve for the team, was of monumental importance in terms of establishing space engineering heritage at UVic for future missions and being able to involve much more students in direct development, manufacturing and integration of flight hardware than other academic developers of CubeSats.

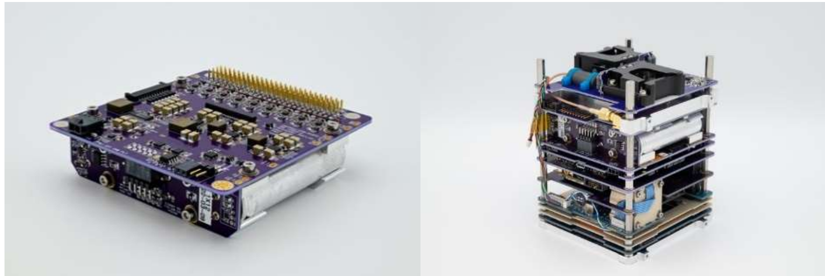

Figure 10 The custom electronic subsystems and bus stack for ORCASat [Alex Doknjas/CfAR]

The development of a custom payload and satellite bus, while a significant undertaking, did not compromise the quality of the final product. Upon delivery of ORCASat, Nanoracks, the launch provider, stated that the spacecraft was in top ten out of 200 all times in terms of quality of workmanship as far as satellites which have been launched by Nanoracks are concerned. Besides the technical abilities and commitments of individual team members, this can be attributed to the fact that the team had excellent faculty support from UVic, and a full time project manager was employed for coordinating the student space engineering activities from the project kick-off until atmospheric re-entry, providing continuity, mentorship, and smooth knowledge transfer for students.

In addition to the spacecraft bus and payload, a custom small satellite ground station was also established on the University of Victoria campus, which was also constructed and licensed by the student team occasion of the ORCASat mission. This station is comprised of a ground station and a network operations center, and it can be securely operated from anywhere in the world. It has successfully served as the only physical control facility for the ORCASat mission for over 600 passes, shown in Figure 11.

Figure 11 UVic ground station (left and center) and operations center. [A. Abuelazm & B. Baldwin / CfAR]

Overall, the ORCASat satellite was successfully operated by the UVic team in LEO orbit for approximately six months. Daily contacts were made with the spacecraft, and many students got introduced to the art and science of satellite operations in the process, resulting in a marked success for the HQP training aspect of this mission. While the demonstration of the reference light source was not successful due to various programmatic and technological challenges, over 25 full time cooperative education students, and over 150 part time volunteers have gained unparalleled experience, growing the next generation of Canadian space scientists, engineers, and entrepreneurs in British Columbia that will change the future of the space industry in Canada.

11. ON-ORBIT EXPERIENCE

Table 2 lists the NORAD ID of each CCP mission and their orbit insertion and de-orbit dates. The two CubeSat in the first batch had an orbit life between 5 and 6 months. In the second batch, it was between 6 and 7 months. In the third batch, the orbit life was between 5 and 6 months. The short duration of the CubeSat missions indicates the solar activity is currently near the maximum.

In the first batch deployment, ORCASat ground station quickly communication with the satellite within the pass. Using the onboard GPS telemetry, the team could use that info to cross calibrate with the TLE released on space-track.org. The team managed to maintain daily operations with the satellite until it deorbited less than 7 months later. One technical problem took the team almost four months to diagnose the issue and came up with a workaround solution. The team noticed that the magnetometer was turned off frequently which required a reboot of the ADCS computer. It turned out it was due to interference from the UHF transmissions that caused the I2C bus communications between the ADCS computer and the magnetometer disrupted. LORIS team encountered technical issues with its ground station and could establish communications occasionally.

The second batch deployment took place on April 24, 2024. The ISS state vectors were provided about 24 hours prior to the deployment. Teams used that information to program their ground tracking antenna. One team seemed to receive the first beacon of its own CubeSat but in subsequent passes, no more contact could be made. The other three CubeSat could not achieve any contact. Three other CubeSat from American universities faced similar issues. Unfortunately, space-track.org did not provide the TLE more than 48 hours later which was a bit unusual. Considering no team was successful in positively identifying its own CubeSat, the assignment of mission name to NORAD ID was not reliable in this case.

On the day of the third batch deployment, there was the Moonlighter mission from Aerospace Corp. Moonlighter team made the contact with its CubeSat while the five CCP teams did not. Although the TLE were released within 24 hours, no CCP team managed to establish contact. One team reported a few contacts with its CubeSat throughout the mission. It should be pointed out that these 5 teams only completed their ground stations after the delivery of their CubeSat for launch. In other words, they did not have the opportunity to carry out a close loop RF test while the CubeSat was still in the laboratory. On the space-track.org site, these 5 CubeSat are still identified as Objects VQ, VR, VS, VT and VV. The association between mission name and NORAD ID in Table 2 below is based on the sequence of deployment.

Table 2 The NORAD ID, Orbit Insertion and De-Orbit Dates of CCP Missions

Mission	Batch	Format	NORAD ID	Orbit Insertion	De-orbit
LORIS	1st	2U	55125	2022-12-29	2023-05-31
ORCASat	1st	2U	55126	2022-12-29	2023-07-07
Ex-Alta-2	2nd	3U	56313	2023-04-24	2023-10-28
YukonSat	2nd	2U	56316	2023-04-24	2023-11-11
AuroraSat	2nd	2U	56312	2023-04-24	2023-10-10
NEUDOSE	2nd	2U	56315	2023-04-24	2023-11-27
SC-ODIN	3rd	3U	57312	2023-07-05	2024-01-08
RADSat-SK	3rd	3U	57313	2023-07-05	2024-01-30
Ukpik-1	3rd	3U	57314	2023-07-05	2023-11-07
ESSENCE	3rd	2U	57315	2023-07-05	2024-01-05
IRIS	3rd	2U	57317	2023-07-05	2023-11-28
Killick-1	4th	2U	TBA	2024-04-18	TBA
Violet	4th	2U	TBA	2024-04-18	TBA
QMSat	4th	2U	TBA	2024-04-18	TBA

12. LESSONS LEARNED

The experience of 15 university CubeSat development, undoubtedly, provides a wealth of lessons learned. A few notable ones are summarized here.

a. *Ground segment must be treated as an integral part of the satellite mission development.*

Among the 11 CubeSat in the first 3 batches, less than 5 had carried out close loop RF test with their ground segment prior to the delivery of the CubeSat. The primary reason was due to a lack of time and the ground segment development was treated as a subsystem that could be completed after CubeSat delivery. When the teams failed to make any contact with the CubeSat, it became hard to identify whether the problem was due to the RF subsystem onboard or on the ground.

b. *Ignoring Lessons Learned is a bad idea.*

Since PDR, CSA team warned the CubeSat teams to avoid the use of I2C bus as there were so many lessons learned indicating issues such as stability issues with multi components connected on the same line. Many teams held the belief that their designs were robust and immune to I2C issues. As discussed above, ORCASat team went through great length in determining the source of the magnetomter shut down was due to I2C interference. Another team learned it the hard way when the issues showed up only when the CubeSat was fully integrated.

c. *Do not underestimate the effort to meet regulatory requirements.*

All the CCP teams utilized amateur radio frequency. At the beginning of the project, the teams had underestimated the time and effort in seeking International Amateur Radio Union approval. Once that step was completed, there was a steep learning curve for the students to learn ITU submission. Finally, they had to file an application for the spectrum license from the national authority. In addition, Canada has the Remote Sensing Space Systems Act (RSSSA) effective since 2007. Broadly speaking, this Act stipulates that any orbiting satellite which has the electromagnetic means capturing the image of the Earth must obtain a license. Since the majority of the CCP missions carried a camera, those teams needed to apply and obtain the RSSSA license prior to the launch of the CubeSat.

d. Leadership makes the difference.

The recipient of CSA grant is designated as the Principal Investigator (PI) who is usually the professor in the institute. In principle, it was the PI responsibility to create and lead the student team throughout the project. A few PIs took full responsibility in all matters related to the project and supervising all students. Since the primary job for the PI remained the teaching duty of the university, this model demanded extraordinary energy from the PI. Many PIs empowered 1 or 2 students and allowed them to lead the students. The PI played an advisor role. However, there were a few PIs took a totally hands-off approach and let the students managed the project themselves. In those cases, it was interesting to see that there would always be one or two students stood up and took over the leadership role. Ultimately, whatever the project management model, the leadership was the single most important factor that contributed the fact that 14 out of 15 CubeSat were completed.

e. CubeSat is the best platform to train space HQP.

Because CubeSat is such a small platform, it was impossible for students to work in silo. For example, a mechanical engineering student would gain experience understanding challenges in electrical, software, thermal and attitude control subsystems. Also, as they worked on an end to end of a satellite project, they gained valuable experience on national and international regulation and guidelines such as spectrum licensing and debris mitigation guidelines. The total cost of CCP, including the launch contract, was below 5M€. The number of students trained exceeded 2,000 and the fact that they all received high quality space training made them appealing to the space industries. More than 100 were hired by space industries immediately and there will be likely more in the near future.

f. Support from technical experts is key in the success of such a project.

With the primary goal of HQP training, it was proved beneficial to support the teams with various activities such as webinar, workshop and more specifically formal reviews such as MCR, PDR, CDR, FRR. In preparation for every review, there was a significant increase in momentum from the teams. By conducting these reviews with CSA experts as reviewers, the students were well prepared for real life scenario in the space sector. Furthermore, support from different space companies in different regions was also beneficial, specifically for some environmental testing.

13. CONCLUSION

This paper presents the Canadian Cubesat Project (CCP) that aimed at training HQP at post secondary level in a complete space mission. 15 universities and colleges across Canada were selected and the initiative was concluded with 14 missions that have been launched in space. Key lessons learned are discussed. The initiative resulted with more than 2,000 students who have gained experience in spacecraft design, build, test and operation. Also, more than 100 of students have now joined the space industry in Canada and 2 start up companies in the space domain were created from CCP students. Novice universities are now ready to train the next generation of space workers with clean room installation and special test equipment, but more importantly new space clubs exist in universities from coast to coast. Due to the success of CCP, the Canadian space agency decided to repeat the experience with another 9 universities working on climate change space mission in a new initiative called CUBICS (CubeSat Initiative for Canadian Students).

14. ACKNOWLEDGEMENT

Throughout the CCP, CSA received significant assistance provided by other organizations and government agencies. First, the support of Radio Amateur Canada (RAC) and International Amateur Radio Union (IARU) in allowing the use of amateur radio frequency by the student teams. The support from Canada Innovation, Science & Economic Development Spectrum Management group, which is responsible for spectrum licensing, is instrumental in allowing the CCP teams able to meet the domestic and international obligations in the use of radio spectrum. Global Affairs Canada provides guidance in the licensing some CCP teams according to the Remote Sensing Space Systems Act. Finally, the team from Nanoracks has provided excellent service to both CSA and CCP teams in ensuring the CCP students delivered their CubeSat meeting the Safety Review requirements.