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Binar Space Program: Binar-1 Results and Lessons Learned

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ABSTRACT

The Binar Space Program is a recently formed space research and education group part of the Space Science and Technology Center at Curtin University in Western Australia. Recently launching the first CubeSat from the state, Binar-1, the team is making steps towards creating a sustainable mission schedule for research and education. The Binar-1 mission primary objective was to demonstrate the custom designed systems made by PhD students and engineers at the university. The main technology being demonstrated was the integrated Binar CubeSat Core, which compacted the Electrical Power System, Attitude Determination and Control System, and flight computer system into 0.25U. Alongside this, the team also aimed to learn about end-to-end spacecraft mission design and engage with the public to build an understanding of the importance of space industry and research in the country. Binar-1 was deployed from the International Space Station on the 6th of October 2021, and initially was silent for 15 days until the Binar team was able to make contact by enabling a secondary beacon. This paper will present the Binar-1 mission including the custom design, operations, failure analysis, and results before finally summarizing the lessons learned by the team while flying Western Australia's first space capability.

INTRODUCTION

With the foundation of the Australian Space Agency (ASA), a new wave of space industry and research has begun in the country. One of the research groups is the Space Science and Technology Center (SSTC) located at Curtin University in Western Australia. With a history in global fireball entry tracking and space situational awareness technologies[1], the research center formed a new branch in the Binar Space Program. This program aims to help develop the skills necessary for working in the space industry by performing valuable space research at the university with frequent CubeSat missions. The first mission performed by the Program, Binar-1, was a technology demonstrator mission that tested the custom designed systems put together by a team of PhD students and engineers.

The design of Binar-1 took inspiration from the first CubeSats developed and launched by universities, focusing on using custom design systems rather than purchasing Commercial Off the Shelf (COTS) solutions. This design decision was made for many reasons; however, the main purpose was to reduce the cost of future missions and build capabilities which can be upscaled to more complex space missions. This technology skill growth has been vital for the team as it now works towards its future missions in Binar-2, Binar-3, and Binar-4.

Having first been conceptualized in the middle of 2018, this paper will present the complete lifecycle of Binar-1. First, the Binar-1 mission goals and design will be detailed. Next, it will discuss the operations, recovery process, and results of the mission. Finally, it will provide a summary of the lessons learned and how these lessons will be implemented into future Binar missions.

BINAR-1 MISSION

Binar-1 was launched from cape Canaveral on the 29th of August 2021 onboard a SpaceX Falcon 9 rocket as a ride share on the International Space Station (ISS) commercial resupply mission CRS-23. The CubeSat was then deployed along with 2 others (Maya-3 and Maya-4) on the 5th of October from the Kibo module and JEM Small Satellite Orbital Deployer (J-SSOD). The launch was coordinated with the Japanese Aerospace Exploration Agency (JAXA) through SpaceBD, a commercial space company in Japan. Figure 1 is a photo taken from on-board the ISS of the CubeSat deployment. Binar-1 can be seen in the top right of the image with the Earth and ISS solar panels seen in the background.

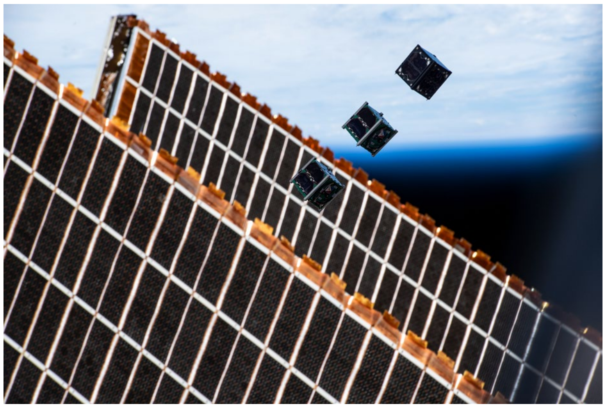

Figure 1: Binar-1, Maya-3, and Maya-4 just after deployment from the J-SSOD with the ISS solar arrays and Earth pictured in the background.

The main objectives of the Binar-1 mission were to:

- Demonstrate the custom designed systems created by the Binar Space Program,
- Educate staff and students about end-to-end spacecraft mission design, and
- Spread awareness about the importance of a space sector in Western Australia.

Alongside these objectives, the CubeSat was also flown with two secondary payloads: an undergraduate student led star tracker, and a high-resolution Earth imagery camera.

Of the custom designed systems being tested, the primary novel system is the integrated Binar CubeSat Core (BCC). Contained inside the 0.25U package is an Electrical Power System (EPS), Attitude Determination and Control System (ADCS), and flight computer system. Also, custom designed by the team was the Binar structure, the Binar Software Framework, and integration method for the communications system and payload cameras.

BINAR-1 DESIGN

The design, testing and integration of Binar-1 took place over the course of 3 years at Curtin University. The initial concept for the design was to make up the satellite from CubeSat COTS systems to meet the mission objectives. This process educated the team on what was typical for CubeSat missions and how to start its own design process. The decision to move to a custom design was made from observations of the COTS solutions architectures and the benefits that could be achieved from a custom designed system. While the systems were modular and made to work together across suppliers, the team noticed that the systems available were not able to achieve the team goals. The system solutions are larger than needed and limited to the design, making it hard for modification to be made without major intervention. Also, the cost of purchasing the systems is greater than if the hardware is custom designed. Moreover, this benefit of custom designing the systems will help the Binar team to reduce future cost and build skills for designing more complex systems in future missions. As such, the team decided to go forward with a custom design due to the many benefits it had alongside the ability to modify and compact the design.

As a result, the custom design of Binar-1 included the BCC, Binar structure, Binar Software Framework, and the payloads. Alongside these systems was a COTS communication system. The system block diagrams for Binar-1 are presented in Figure 2, separated into its power and signal connections.

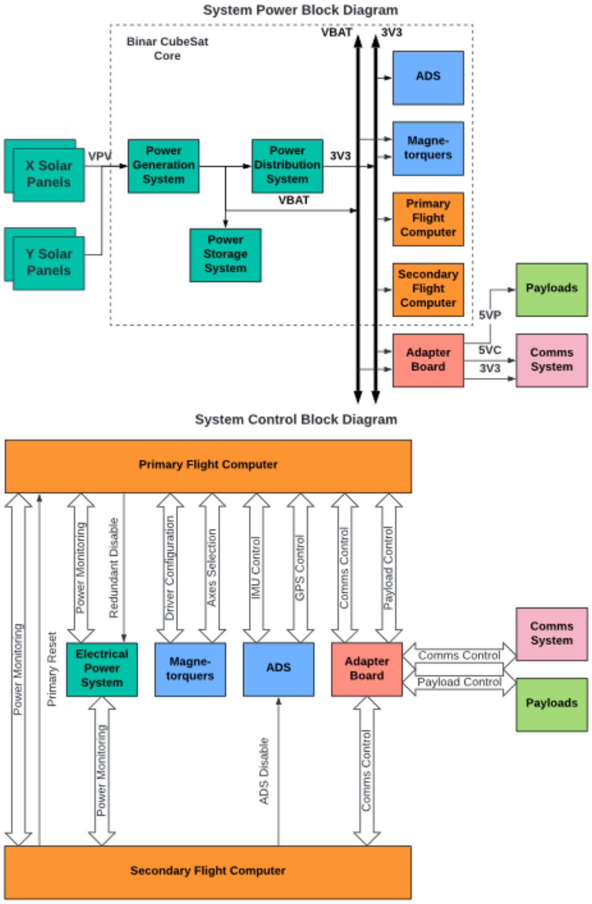

Figure 2: Simplified Binar-1 system block diagrams.

Binar CubeSat Core

The integrated BCC is the primary technology demonstrator objective of Binar-1. Containing the integrated EPS, ADCS, and flight computer system, the goal of the design was to compact these systems to make more space for payloads. Learning from the initial Binar-1 design which used COTS systems, the primary requirements for the BCC were based around compactness, safety, reusability, reliability, and testability. The complete design was achieved using computer aided design software, allowing for optimal placement of electronic parts and mechanical structures.

The EPS found on the BCC contains the typical subsystems of an EPS including a power generation subsystem, power storage subsystem, and power distribution subsystem. The power generation subsystem consisted of two Maximum Peak Power Controllers (MPPC) which are supplied from solar panels on the X and Y faces of the CubeSat. The solar panels were assembled by the Binar Space Program, making modifications to existing assembly methods to optimize and simplify the process for 1U panels[2]. Connected to the power generation subsystem, the power storage subsystem consisted of four lithium-ion 18650 battery cells in a 2S2P configuration. To meet the mission and launch safety requirements, the power storage subsystem also included battery heating and an ISS launch qualified battery protection system. Finally, the distribution subsystem consisted of a dual redundant 3.3V converter to power the remaining systems on the BCC. The distribution subsystems for the payloads and communications system were found on the adapter board which connected the BCC to the PC104 connectors used by the COTS communication system.

The ADCS contained on the BCC consisted of an Inertial Measurement Unit (IMU), Magnetometer, Global Positioning System (GPS), and a 3-axes magnetorquer. Combining the complete system into the BCC, the EPS and flight computer system were able to integrate with the ADCS from the beginning of development. This process helped to remove integration issues and increase confidence in the design. The IMU and magnetometer were used for feedback in the attitude control system and operation of the magnetorquers. Integrated with the batteries inside the 0.25U BCC, the magnetorquers consisted of two X and Y axes iron core magnetorquers and one large Z axis vacuum core magnetorquer. These coils are all operated by driver circuits located on the BCC.

The flight computer system consists of two flight computers, one primary and one secondary, as well as an external memory device. The system uses the primary flight computer for all flight operations and control, relying on the secondary flight computer only if the primary flight computer fails. The external memory device provides 4GB of on-board payload and system log storage for the primary flight computer which can be requested from the ground via telecommand. Housed around the BCC is part of the Binar structure including the RBF bracket, magnetorquer mount and top cap. These all fit inside the rest of the Binar structure detailed in the following section. A BCC that was used for lab testing is presented in Figure 3. Due to the reduced hardware cost of the BCC, the team was able to assemble multiple versions of the core for integration testing and verification.

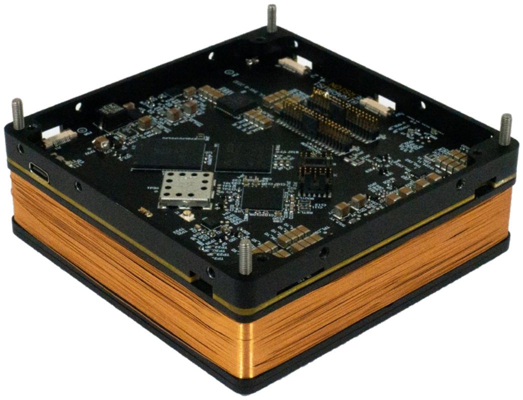

Figure 3: A flight model equivalent of the Binar CubeSat Core (BCC) that was used for lab testing.

By combining three of the main systems of a CubeSat into a single core, the Binar team was able to meet its design requirements. The compact design compared to the original COTS Binar design has allowed the team to increase its payload space, which in turn will benefit the team in future missions when reused. Safety has been implemented, protecting the batteries from accidental shorts or over charge and over discharge conditions. Reliability was implemented with extensive integration testing during design iterations, and simple additions of redundancy were possible. The testability of the design is also made easier through the combination of the Binar Software Framework which was designed to work with the BCC. This direct access to BCC is what will enable the Binar Space Program to fly more complex payloads on future missions.

Binar Structure

The Binar structure was designed by the Binar team to meet the launch requirements of the JEM Payload Accommodation Handbook Vol 8. Rev D[3]. The structural design consisted of two rail halves which were connected to the BCC in the center. The antenna and payload were then used to constrain the satellite at the top and bottom. This design was able to meet the launch requirements due to the tight tolerancing of the BCC holding the satellite together. Other parts of the structure included those found in the BCC and the payload mounting plate. The mounting plate was designed to also act as a counter mass for the BCC to move the center of gravity as close to the geometric center of the satellite as possible, assisting with the attitude control system. The exploded view (Figure 4) presents the structural design of Binar-1. The exploded BCC seen in the center connects to the adapter board and transceiver forming the stack. This was then fastened to the two main rail halves which form the structure. The antenna, payload and solar panels were then fastened to the six sides of the CubeSat.

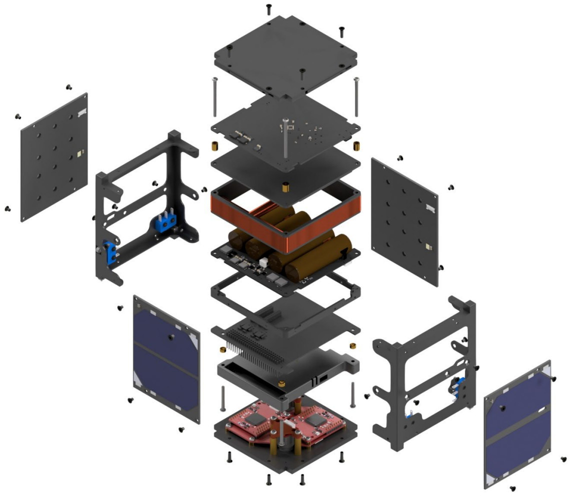

Figure 4: Exploded view of Binar-1

Binar Software Framework

Matching the hardware design goals of creating a safe, reusable, reliable, and testable platform, the Binar Software Framework was written to enable rapid mission concept-to-orbit. Specifically structured around areas that commonly contribute to software related mission failures, namely insufficient software testing, lack of documentation, unsafe code reuse and cursory code review, the Binar Software Framework has provided the Program with a reliable code base that can be reused on future Binar missions.

Comprising of flight application code, a hardware abstraction layer, utilities, resource manager, and board support layer, the codebase adheres to an abstracted software design that enables hardware to be changed with only minor modifications to the software. Moreover, the loose module coupling within the abstracted design allows hardware dependencies to be broken during unit testing to increase the testability of the code base.

Communications System

The communications system on Binar-1 was the only system that was supplied by a COTS provider. The decision to use COTS for this part of the satellite was based on the team size and amount of experience. At the time of decision, the small team was only made up of PhD students and part-time engineers. With significant focus on developing the BCC, Binar structure, and Binar Software Framework, the team was unable to commit the time to learn about communications design. As such it was decided that the best course of action for the success of Binar-1 was to purchase a COTS communications system.

The data requirements for transmitting the flight logs and payload images were achievable with a UHF communications system. The team decided to use the COTS system recommended in the initial COTS design of Binar-1 to meet this requirement. The deployed antenna can be observed in Figure 5. As the BCC was not based on the PC104 standard to optimize its space efficiency the team used an adapter board to connect the two together. This board was also used to adapt the BCC to the payloads.

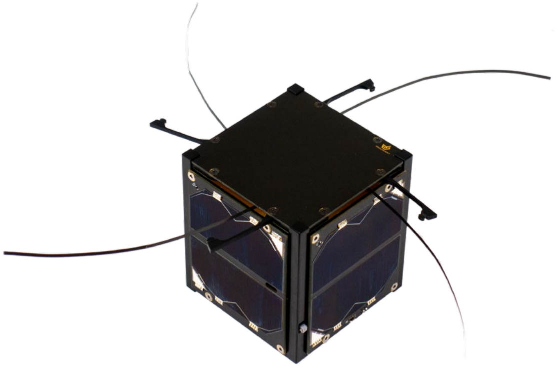

Figure 5: The Binar-1 engineering model with the antennas deployed.

Payloads

Two payloads were flown on Binar-1 including a high-resolution camera for Earth imagery of Western Australia and a student led star tracker camera for developing more precise attitude determination capabilities at the Binar Space Program. Both payloads were originally planned as primary mission objectives, however, after the change to a custom design, the purpose of the payloads shifted to demonstrating the functionality of the BCC and its ability to operate payloads. The payloads were integrated together with a custom PCB that connected to the same adapter board used by the communications system. The two cameras were both COTS cameras, the first being selected by the Binar team to give the best resolution for Earth imagery in the available payload space (80m/pixel), and the other being a low-resolution camera that was selected from a range of cameras tested by the team of undergraduate students. The final payload system was mounted to the bottom of the satellite.

Ground Segment

As part of the mission plan for Binar-1, the team also needed to develop its own ground station (Figure 6) and operation software for the Binar-1 mission. Made from a combination of custom and COTS components the Binar ground station was built and placed on top of the engineering building on the Curtin University Bentley campus. The operating software was designed as part of a collaboration with Fugro Space Automation, AI, and Robotics Control Complex (SpAARC). The complete design was tested on existing satellites in LEO in preparation for the deployment of Binar-1.

Figure 6: The Binar ground station located at the Curtin University Bentley campus in Western Australia.

INTEGRATION AND TESTING

Integration and testing of the Binar-1 flight model was conducted using the facilities available at Curtin University. Testing was separated into two parts, being the integration and testing performed on the custom designed systems and the testing performed to meet the launch requirements. The regulatory requirements necessary for launch are documented in the JEM Payload Accommodation Handbook Vol 8. Rev D. which included battery safety testing, vibration testing, and interface verification testing.

Binar Testing Procedures

To verify the functionality of the custom Binar-1 platform the team developed testing processes throughout the course of the design. One of the main testing processes that was developed was the integration testing process of the BCC. A benefit of the integrated design was the straightforward process of verifying the connections and operation software for each system on the integrated core. This helped to build confidence in the hardware and software design as faults were identified and removed early in the custom design process.

Typical to CubeSat testing programs, the team performed thermal vacuum testing using a modified vacuum chamber at Curtin University (Figure 7). The modification included a liquid nitrogen shroud and electric heater which can reach surface temperatures of -100°C to +150°C. Testing in this chamber was also verified with a test using the Wombat XL located at the National Space Test Facility (NSTF), Australian National University (ANU), in Canberra. The verification test was done before the assembly of the flight model using the Binar-1 engineering model. Results from this testing was important to verify the modified vacuum chamber due to the COVID-19 pandemic restricting the ability of West Australians to travel without quarantine. This meant the team could not return to Canberra to perform the vacuum testing again with the flight model.

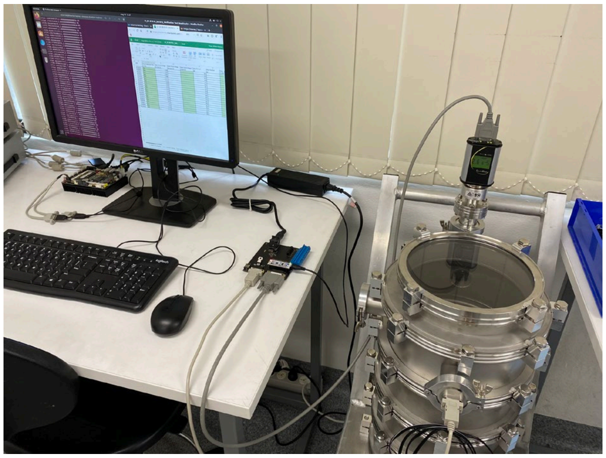

Figure 7: Vacuum testing performed at Curtin University.

Although the team would have liked to have performed more testing on the BCC and Binar-1, challenges with the communication system and a misunderstanding of changes in the regulatory requirements led to delays in the design and integration process, reducing the available testing time of Binar-1. Changes in the launch regulations meant that the antenna needed to be modified and re-tested to include two burn wires. This change was necessary due to the requirement for inadvertent antenna deployment inside the J-SSOD having its maximum allowable force reduced to below the force exerted by the COTS antenna. The schedule was also affected by a difference in the engineering model COTS UHF transceiver and the flight model COTS UHF transceiver. To reduce cost the team purchased a 1W variant of the transceiver for the engineering model and a 2W variant for the flight model. Due to a misunderstanding of documentation, it was unknown to the team until the beginning of testing the flight model transceiver that I2C was not usable on the 2W variant. This added to the delays as a new adapter board had to be made to change the connection to the transceiver.

As a result, only the very basic system level verification was performed on Binar-1 between the BCC and the transceiver alongside the necessary regulatory testing requirements. This means that only the beacon, detumble, and basic telecommands of Binar-1 was tested before launch, and no full Day-In-The-Life (DIL) testing could be completed as planned. One observation that was noted in the basic system testing was another challenge involving the UHF transceiver. A difference in receiving power usage from the datasheet was noticed which effected the power budget. The team decided that it was still in the best interest of the program to continue with the launch and perform a system update early in the mission to reduce the power usage of some of the other systems.

Regulatory Testing Requirements

The main regulatory testing requirements necessary for Binar-1 to meet were included in the safety review process. This included testing all the systems of Binar-1 that could cause damage to the launch vehicle, ISS, or astronauts on-board. The most significant of these tests was the battery verification testing, safety inhibit testing, and the vibration testing.

The battery verification and safety inhibit testing was the critical path of the Binar-1 assembly and testing process. Requiring a batch qualification of the lithium-ion cells on Binar-1, the process was time consuming due to the lack of resources able to perform the tests. After qualification, with flight model cells approved, the battery safety inhibits required testing as well. This included a short-circuit test, over-charge test, over-discharge test, switch inhibit test, and insulation test. These tests were performed at various stages of the assembly and integration procedure. After the complete assembly, a final battery cycle test was required before and after the vibration testing to finally verify the structural integrity of the battery cells and qualify for launch.

Vibration testing was performed at Curtin University using the available facilities. Similar to other CubeSat launches to the ISS, Binar-1 was qualified to all possible ISS resupply mission launch vehicles. The final testing before delivery was important to ensure that the satellite had been assembled correctly and that the antenna modification would not inadvertently deploy inside the J-SSOD.

MISSION OPERATIONS AND RESULTS

Deployed from the ISS at approximately 5:20pm (AWST) on the 6th of October, Binar-1 was required to wait 30 minutes before deploying its antennas and starting to beacon. The first possible attempt at receiving from the ground station in Western Australia was expected at approximately 11:00pm (AWST) however, the team also planned to use the SatNOGS[4] service to look for signals earlier. The beacon string contained the satellite name, GPS data, critical power and temperature information, and a unique message from the Binar team. Unfortunately, no communications were received on the first pass, or on any of the SatNOGS passes. This prompted the team to start attempting to communicate with the satellite and search the sky for its location. However, these attempts soon ended as the other two CubeSats launched along with Binar-1, Maya-3 and Maya-4, successfully established contact within the first day of operations, successfully confirming the expected location of Binar-1. As such, this prompted the team to start a failure mode analysis to determine if a recovery could be made.

Failure Mode Analysis

A benefit of the Binar-1 custom design was the knowledge of the system available to the team. By stepping through how the satellite would behave after deployment, the team was able to closely analyze the possible operation paths and determine if any possible software bugs or hardware failures could have caused the communication silence.

The first step of the failure analysis and the starting point for operation was the EPS. Being one of the most common reasons to failure[5], and necessary for powering the rest of the Binar systems, the EPS had been heavily tested throughout the design process. One possible failure point was found involving an interaction between the power distribution subsystem and the flight computer system. When the flight computer booted, one of the first actions it performs was to disable the secondary distribution subsystem. Before performing the task, the flight computer sets a system flag into memory and then resets it after the task is complete. If the system power cycles after disabling the redundant distribution subsystem, then at re-boot the system flag should still be set, and the flight computer will know that the redundant distribution subsystem is being used. However, a flaw was found in that the flag was being set in volatile memory causing it to reset if power was lost to the flight computer. This would have resulted in a flight computer power cycling event where it would continuously disable the redundant distribution subsystem. This flaw was found to not be the reason for failure due to the next attempts made by the team, however it was still an error that needed to be corrected in future implementations of the BCC.

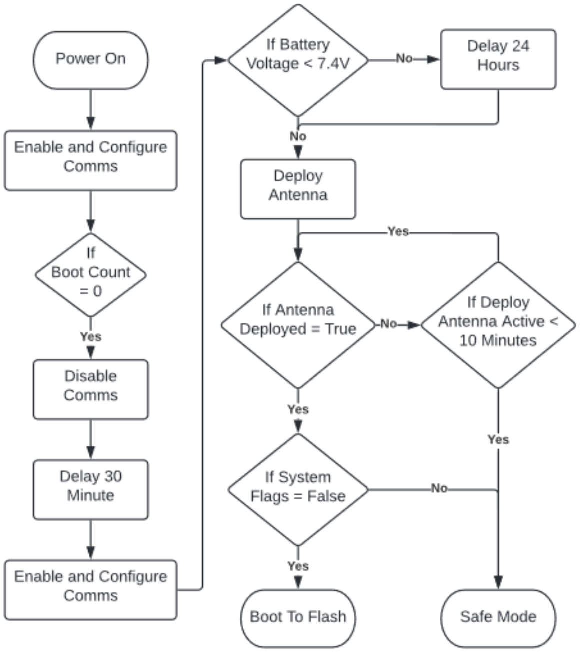

Figure 8: Binar bootloader software flow chart.

To continue the failure analysis process, the team assumed the flight computer system still had power. From here the team analyzed the flight software to determine if any logic errors or bugs had gone unnoticed since delivery. First the 30-minute wait must occur after deployment where the communications system is powered off. After the 30-minutes, the communications system is powered on, and the antennas deployment circuit will activate if the satellite has over 50% battery. The deployment burn wires will be switched on until the successful deployment condition is met, or until the 10-minute timeout is reached. If the battery is less than 50% then the satellite will wait for 24 hours before attempting the deployment. After this, the bootloader makes two system checks before deciding to boot into application code or safe mode. The first check is the system critical checks. This check will scan the system flags for any reported faults. These flags are only set in the system critical check application in application mode or in safe mode. This means that during the first boot, this check will always pass. The other check that is performed is a check on the antenna deployment condition. If the antennas did not deploy correctly then the CubeSat would be put into safe mode, where a beacon would be broadcast at reduced frequency to conserve power. The flow chart for this process is summarized in Figure 8.

During testing, safe mode was tested by disabling the 30-minute wait time, disabling the 10-minute time out of the antenna deployment system, and holding down the deployment sensor switch. This was done to conserve time in the Binar testing program due to the schedule losses mentioned previously. As a result, when testing the satellite would boot directly into safe mode so that the functionality could be tested. In testing, these beacons were received correctly however, this was only observed when the delay timers were not enabled. In this state the software would enable and configure the communications system before jumping straight into safe mode. However, if the communications system doesn’t receive any signals for 255 seconds, the configuration is reset to its default mode. This is where a software logic error was found as when the timers are enabled, and if the antennas didn’t deploy within 255 seconds, then the communications system would not be configured properly. To test that the error existed, the team performed a test with the engineering model and verified that this was a possibility for failure on Binar-1.

Another theorized possibility is that the antenna did deploy correctly and boot into the flash application software operation mode. In the application mode, the communications system would have been configured again however, the theory was put forward that the poorly tested adapter board, that had a last-minute modification, had failed. Due to the nature of the last-minute modification, the board was not thermal vacuum tested or vibration tested correctly which could have caused a solder joint to break meaning that the flight computer was potentially not able to communicate with the communications system or power it.

Fortunately for the Binar team, if the COTS communications system was powered and in its default mode, it could be configured from the ground. As a result, the team concluded that the best action would be to attempt to send the configuration commands to the satellite and see if the beacon could be received. After first confirming with the engineering model that this was possible, the team attempted to communicate with the communications system hoping that the adapter board was operating correctly.

Partial Recovery

To attempt the recovery, first the team attempted to configure the communications system in the required mode for the safe mode beacon to be received. These attempts were made over multiple passes to no success. It is still unclear as to the team on whether commands were received by the satellite or not as it depended on how many of the antennas were deployed, the attitude of the satellite during the passes, and if the adapter board was operating properly.

With these attempts not being successful, the team decided to attempt to put the COTS communication system into its own beacon mode. This beacon mode was built into the system and could be configured in a similar way to the desired configuration. The attempts to enable this mode were successful on the first attempt, partially recovering the location and status of Binar-1. The first beacon was received at approximately 5:21pm (AWST) on the 21st of October (Figure 9), almost exactly 15 days after the deployment from the ISS. The beacons enabled were operating with a shorter period and lower bit rate to try and help the team to locate the satellite on more ground station waterfall plots using the SatNOGS network.

One of the risks of enabling the shorter period beacon was that the power balance of Binar-1 would not be stable from the increased frequency of the beacon. As a result, the team needed to turn off the beacon as soon as possible. Unfortunately, the team was unable to turn off the beacon on the first attempt and was only able to switch the beacon into a shorter period mode 23 hours after the first signal had been heard. During this time, the beacon was seen around the world on the SatNOGS website before the beacons started to appear with a longer period. The longer period beacons were seen for another 11 and a half days until Binar-1 made its final recorded transmission at approximately 7:03am (AWST) on the 2nd of November. Although the team made many attempts to recover the satellite again after this date, it is suspected that the satellite ran out of charge at this point due to a combination of the compromised power budget and constant power cycling causing start-up applications to run regularly. The power cycling could be observed as the message contained in the beacon would revert to the default message. Another observation that was made was the bit rate of the beacons not being re-configured when the power cycle occurred. This led the team to believe that the cause of failure was likely due to the adapter board.

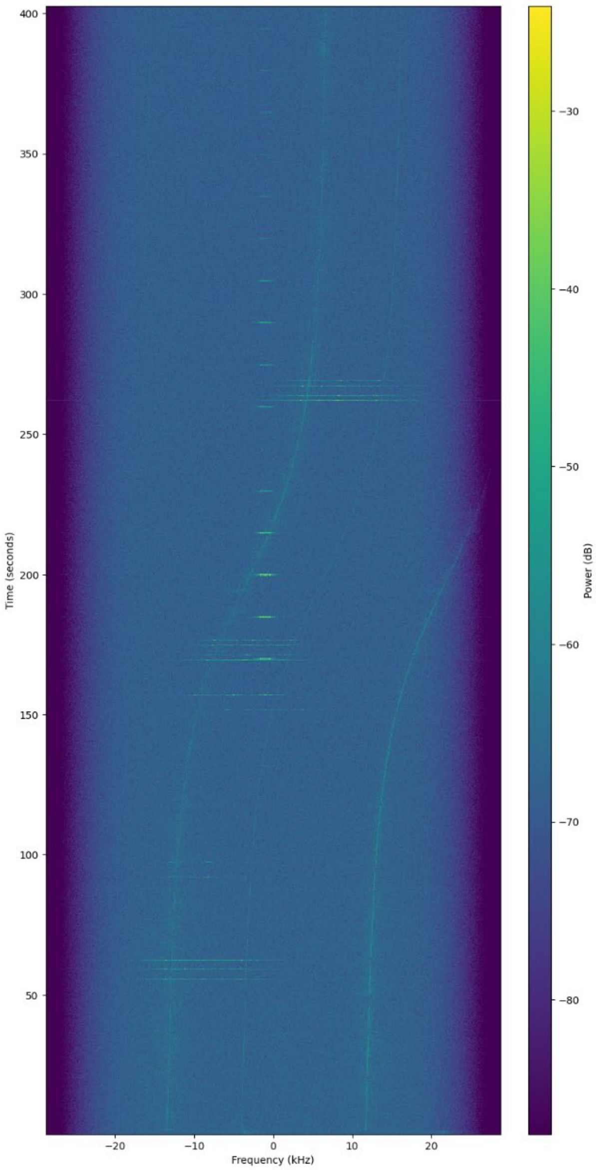

Figure 9: SatNOGS plot from the first observed communications with Binar-1. The wider signals are the transmissions from the ground station.

Results

From the failure analysis, the team believes that the last-minute adapter board modification was the cause of the lost communications with the flight computer. This belief comes from the beacon bit rate not being reset when the communications system was being power cycled, suggesting that the connection between the flight computer and the transceiver were not made correctly and likely broke during vibration testing, launch, or when exposed to the environment of space.

Although only a partial recovery was made, the Binar team was still able to infer some of the operations of the BCC from the beacon mode activated on the transceiver. It was clear to the team that the EPS was able to power the BCC until the final communication was made. Knowing the power budget problem before launch it is clear to the team that the solar panels, MPPTs, batteries, battery heaters, and the distribution subsystems were operational to some extent. The flight computer was also operating as expected as it was turning the communications system on. Alongside these two systems there was also valuable knowledge gained about the deployment switches and the performance of the structure during launch and in space. All of this could only be learnt by the team by delivering the mission.

LESSONS LEARNED

Although the mission was only considered a partial success in terms of the technology demonstration objective, the goal of educating staff and students was considered a success in terms of the many lessons that have been learned in the design process. Being a team starting with no knowledge about spacecraft design, the mission was always going to be challenging. The value of the lessons learned will help the team to overcome these challenges on the next launches from the Binar Space Program and be passed down to new students and staff beginning to work on the project. Although some of the lessons learned may not be new to more developed CubeSat design teams, the team believes that sharing the lessons learned will continue to build the literature around CubeSat design and hopes to help those who are yet to start the design process.

The first lesson learned by the team was the importance of locking down high-level mission objectives at the beginning of the design process. Although this is challenging when first starting the design, if possible, settle early on the budget and mission objectives. With these refined, defining requirements to meet the objectives is made easier. If the mission objectives are changed, start the process again and perform design reviews again if the objective changes are significant. One advantage of the decision to perform a custom design was the ability to easily adapt the design to some of these changing requirements, however this still meant that work needed to be repeated every time a change was made, significantly impacting the launch schedule.

Although power budgeting was performed in detail, the budget was only tested with the engineering model, and not to a suitable level of detail due to the missed DIL testing with the flight model. To improve its practices in the future the Binar team has learned to perform tests as you fly and not alter the engineering model to save costs. This costly operation may have been detrimental to the Binar-1 mission as the unbalanced power budget caused by the communication system was likely one of the reasons for communications loss.

Due to unexpected delays in the assembly process some testing was cut short. The team learned that it could be far better prepared for unexpected delays and prioritize its test program better if delays occur. Implementing this into the program will help to assess launch risk, and better manage the decision to either delay launch or remove some testing processes and assess the risks. Being able to present this plan to the mission leaders prior to the assembly can also help to better prepare the leadership team for delays and risk acceptance.

Although parts of the assembly and testing were shortened to make the launch, the team learnt important lessons about operation planning at the deployment of Binar-1. It was overlooked by the team the importance of putting in place an operations plan and setting up times for observations. This is something the team hopes to integrate into its DIL testing in the future to improve the performance of the operations plan and ready the team to operate the next set of Binar CubeSats.

The final lesson learnt relates to the goals of the Binar Space Program and the achievements observed by designing and assembling the satellite as a Program. Through the custom design, the Binar Space Program has learned and benefitted during the design and will continue to benefit in its future designs in different ways to how COTS comprised CubeSats benefit. This lesson will continue to be implemented by the Binar Space Program as it progresses into the future, aiming to work on its own payloads and platforms to continue building design experience at the university so that it will be able to deliver more complex space missions in the future.

CONCLUSION

Binar-1 was the first CubeSat launched by the Australian state of Western Australia. The custom designed CubeSat primary objective was to demonstrate the functionality of the integrated Binar CubeSat Core (BCC) which consisted of three of the satellites main systems including the Electrical Power System (EPS), Attitude Determination and Control System (ADCS), and flight computer system. The other objectives of the mission were to provide education to staff and students about end-to-end spacecraft design, and to spread awareness about the importance of space research and industry in the state.

After being deployed from the International Space Station (ISS) on the 5th of October 2021, Binar-1 was radio silent for almost exactly 15 days until a secondary beacon was enabled by the team. The secondary beacon was observed around the world by the SatNOGS network, until it stopped 11 and a half days later on the 2nd of November. This result has partially achieved the primary mission objective of the Binar-1 satellite demonstrating that the EPS and flight computer system on the BCC were operating in space, however no flight data could be collected to verify the systems completely.

Binar-1 has been successful at educating staff and students about end-to-end spacecraft design and provided a range of lessons learned which will be used in future Binar launches. These lessons include locking down mission requirements early, performing power budget testing with flight model systems, preparing for testing delays, planning for satellite operation, and the importance of using custom designed systems when aiming to perform consistent CubeSat missions.

Having learned these lessons and partially demonstrating the BCC, the team is now moving forward with implementing the lessons learned on its future missions. This will continue to grow the awareness of space in Western Australia as the team aims to deliver three 1U CubeSats, Binar-2, Binar-3, and Binar-4, in its next launch planned for 2023.

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