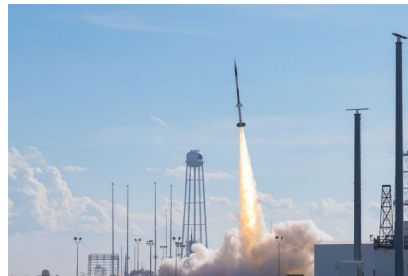


GHOST (Grand cHallenge MesOsphere Student rocketT)

User Guide



A student rocket launch in partnership with NASA's Wallops Flight Facility (USA), Andøya Space (Norway), and the RockSat-X program



Wallops Flight Facility (WFF)
Wallop Island, Virginia



Andøya Space (ASP)
Andøya, Norway

0.0 APPROVALS AND TRACKING

0.1. Signatures

Prepared &
Approved by: _____
GHOST RockSat-X Program Manager

WFF Concurrence: _____
Sounding Rockets Program Office

AS Concurrence: _____
Andøya Space

0.2. Revisions

Revision	Description	Date	Approval
Draft	Initial release		

Table of Contents

APPROVALS AND TRACKING	2
Signatures	2
Revisions	3
INTRODUCTION	6
RockSat Program	6
Participant Eligibility and Responsibility	6
Purpose	7
Getting Involved (Intent to Fly Forms)	8
Experiment Space	8
Refund Policy	9
Points of Contact	10
Applicable Documents and Links	10
ROCKSAT-X OVERVIEW	10
ROCKET DESCRIPTION AND CAPABILITIES	12
RockSat-X General Capabilities Description	12
Rocket Key Performance Parameters	13
Flight Environment Conditions	14
G Loading	14
Flight Environment	14
Disclaimer	15
ORGANIZATIONAL RESPONSIBILITIES	15
Customer and WFF Responsibilities	15
Ground Control	16
PAYLOAD DESIGN AND INTERFACE REQUIREMENTS	16
Constraints On Experiment Types	16
Mechanical	16
Physical Envelope	16
Mechanical Interface	17
Mass Properties	20
Center of Gravity	20
G Loading	20

Material Selection	21
Heat of Reentry	21
Power and Telemetry	22
Power and Telemetry (PT) Interface	22
PT Interface Design	22
Electrical Interface	23
Power Provided and Activation	25
Independent Power Sources	26
Telemetry Provided	27
Telemetry Interface	27
Asynchronous Framing and Baud Rates	28
Space Environment	29
High Voltage	29
Electrical Harnessing and Staking	29
Radio Frequency Transmissions	30
Summary of Key Constraints	30
EXPERIMENT HARDWARE INTEGRATION	31
EXPERIMENT TEST REQUIREMENTS	31
Structural Testing	31
Vacuum Testing	31
Day in the Life Testing (DITL)	31
Wallops Flight Facility Testing	32
June Integration and Environmental Testing	32
August Integration and Launch	33
SELECTION PROCESS	33
SCHEDULE	35
10.0 APPENDIX A: Mechanical Drawings/Interfaces	36
APPENDIX B: Environmental Testing Characteristics	38
APPENDIX C: Supplemental Telemetry Specifics	39
APPENDIX D: Summary of June Testing Operations	40

1.0 INTRODUCTION

1.1. RockSat Program

GHOST is the second partnership with Wallops Flight Facility (WFF), Andøya Space (ASP), and the RockSat-X program, which is designed to give students access to space. GHOST is structured around the USA version of the RockSat-X program, with changes to location of launch, program timeline and requirements, and without vehicle attitude control system (ACS) or vehicle recovery. GHOST will be run in the same way as the USA RockSat-X program, with design and test reviews with the RockSat-X Program Manager, and integration and testing in August of 2024. GHOST will provide full access to the space environment opening the door for students to design and conduct unlimited experimentation in the M/LT region.

All of the student teams shall follow the schedule and provide all the presentation and document deliverables as described in this User Guide. All teams will be managed by the GHOST RockSat-X Program Manager regardless of their country of origin. The following image shows the program leadership flow (TBD)

There will not be an Attitude Control System (ACS) on the GHOST launch vehicle and experiment sections will not be recovered/rescued upon landing. After August 2024 integration at WFF, the integrated launch vehicle will be shipped to Norway in September 2024 to be launched in November 2024.

1.2. Participant Eligibility and Responsibility

The intent of the GHOST program is to provide hands-on experiences to students and faculty advisors from educational institutions to better equip them for supporting the future technical workforce needs of the United States and other participating countries and/or helping those students and faculty advisors become principal investigators on future NASA or other space agencies/institution science missions.

For the purpose of GHOST, 'educational institution' is defined broadly and includes, but is not limited to, the following: universities, colleges, technical schools, public and private high school, middle school and grade school, science museums, etc. Organizations, which are not included in the above listing, are encouraged to contact the RockSat-X Program Manager at rocksatprogram@gmail.com to clarify their eligibility in the program. Since the focus of GHOST is international, USA and international entities (e.g. industry, research institutions, etc.) that fall outside of the eligibility conditions listed above, but who are interested in participating in the program, are encouraged to team with an eligible USA and non-USA educational institutions. Teaming between educational institutions and industry or other interests is allowed and encouraged. However the experiment shall be a student project with students doing the design, build, test, documentation, operation, and data analysis.

Participation in the GHOST program includes video teleconferences with WFF employees and contractors as well as all integration, testing, launch, and recovery operations that take place at WFF. Normal access to WFF facilities and personnel is limited to U.S. persons only. An exception will be made for the GHOST program only, and will not carry over to the standard RockSat-X Program.

Additionally, participants in the GHOST program shall comply with export regulations in regards to disclosures of technical data. All participants warrant and represent that they will limit disclosure of any technical data contained in, made available, or generated in the performance of their participation in the GHOST program in accordance with export restrictions imposed by the U.S. Export Administration Regulations, 15 C.F.R. Parts 768 et seq. and the International Traffic in Arms Regulation, 22 C.F. R. Part 120 et seq. This applies to all parties involved (such as an industrial partners to an educational institution). ***Further guidelines for non-USA based teams regarding this matter will be provided and discussed after those teams submit their Intent to Fly Forms and the country or the countries involved are determined.***

1.3. Purpose

The purpose of this document is to identify the interfaces, requirements, and logistics pertaining to the GHOST WFF/ASP/RockSat-X program. This document also establishes the guidelines and requirements for qualifying an experiment for selection to be flown, along with the review and integration schedule. Experiments shall be student based with faculty and/or industry involvement only. GHOST is not available to experiments that are profit related endeavors and/or solely industry research and development. Students shall be actively engaged and involved.

1.4. Getting Involved (Intent to Fly Forms)

Interested institutions/teams shall submit an Intent to Fly Form (IFF) on April 17, 2023 at 5 PM MDT in order to be considered for participation in the GHOST program. The IFF can be found here. <https://tinyurl.com/ghost-iff> Although required, submission of the IFF does not mean that your team has been selected for flight on the GHOST program. Due to the limited experiment space on the launch vehicle, a down-selection process may be utilized after the successful completion of the GHOST Conceptual (CoDR) and Preliminary (PDR) design reviews.

1.5. Experiment Space

There are six full experiment spaces on the GHOST rocket. Five in the aft of the rocket and one in the nosecone. These full spaces are allocated power, volume, weight, and power as described in the sections below. Teams can elect to use half of a full aft experiment space however the power and telemetry connections along with the weight and volume limits are reduced to approximately half of the full space limits. Specific allocations will be discussed with teams after the flight manifest is finalized after PDR. Half experiment space customers cannot use more than half the battery capacity. Telemetry lines must also be shared, but the RockSat-X Program Manager will do their best to partner shared customers so that both experiments can utilize all the telemetry lines that have been requested. Note that it is not guaranteed all the customer's requested telemetry lines will be granted. In the event that a subset of customers would like to redistribute allotments, all customers of the subset must contact WFF, and changes will only be made with written approval of all parties involved and WFF. The five full experiment spaces cannot be split into any size smaller than half. The nosecone space cannot be split.

1.6. Program Fee

The GHOST Program Fee pays for the GHOST Program. It covers the costs to administer, run, and manage the program which begins with reviewing the IFFs and ends with the review of each team's final report. The Program Fees

are used as teams progress through the program and are therefore non-refundable. See additional details below. The Program Fee associated with GHOST is contingent upon the amount of the experiment space being utilized. Teams will receive (1) RockSat-X experiment deck with power and telemetry interface connectors after their final of 3 payments has been made. Additionally, teams will receive 8 program t-shirts during the November launch trip. Travel costs to and from Wallops Flight Facility and Andøya Space, lodging, meals, or other expenses incurred while supporting these trips are the responsibility of the teams. The Program Fee does not cover any hardware costs for the team to build their experiment.

The Program Fee for a full experiment space is \$30,000 USD. The Program Fee for a half experiment space is \$18,000 USD. The Program Fee is to be paid in 3 payments based on the schedule below. Payments shall be made by check, Purchase Order, wire transfer, or credit card. Details on where to send payment will be provided on the invoice. Payment is NET 30.

Invoice Date	Due Date	Payment Amount	Notes
07-16-2023	08-16-2023	Full = \$10,000 USD Half = \$6,000 USD	
10-29-2023	11-29-2023	Full = \$10,000 USD Half = \$6,000 USD	
03-03-2024	04-03-2023	Full = \$10,000 USD Half = \$6,000 USD	Decks and connectors sent after this payment
	Totals	Full = \$30,000 Half = \$18,000	

1.7. Refund Policy

The Program Fee is only refundable if a team is down-selected on September 22, 2023. Teams not selected for flight during this process will receive a full refund of program fees paid minus a small processing fee. Teams selected for flight will be responsible for completing their remaining payment by the due date. Additionally, launching rockets has inherent design issues, schedule risks, technical unknowns, and weather factors. While launch of the RockSat rockets is the intention of this program, it is not guaranteed. If in the event that the rocket is unable to launch due to any factor listed above or for some other reason beyond Wallops Flight Facility and/or Andøya Space control (this has never happened), experiments will be returned to teams and there will not be a refund of the program fee. After launch, the rocket is not

recovered after launch and no compensation will be made for the experiment hardware. If WFF, ASP, or the RockSat-X Program Manager determines your team is non-compliant with the GHOST User Guide at any time (if possible, teams may be given time to become compliant) and/or if your experiment fails a pre-launch delivery and/or testing benchmark, you will be removed from the flight manifest. If integration to the rocket has already occurred, your experiment may still fly as an inactive experiment or it may be returned to you. In both cases, you will not receive a refund of the program fee.

1.8. Points of Contact

At this time, RockSat Points of Contact (POC) are still being determined. For now please direct all inquiries to rocksatprogram@gmail.com

1.9. Applicable Documents and Links

- Sounding Rocket Program Office - Student Flight:
<https://sites.wff.nasa.gov/code810/student.html>
- NASA Wallops Flight Facility:
<http://www.nasa.gov/centers/wallops/home/index.html>
- NASA Sounding Rockets User Handbook
<http://sites.wff.nasa.gov/code810/files/SRHB.pdf>

2.0 GHOST/ROCKSAT-X OVERVIEW

The GHOST/RockSat-X experiment deck is a modular system based around experiment decks designed for suborbital flights with the WFF RockSat-X experiment section called the Carrier of Rocket Learning Laboratories (CarRoLL). Figure 2-1a and Figure 2-1b (below) show the CarRoLL structure and plate layout, respectively. Figure 2-2 and further details on the RockSat-X mechanical interface can be found in Appendix A and auxiliary reference document: RS-X Mechanical Interface. **Nosecone experiment section details forthcoming.**

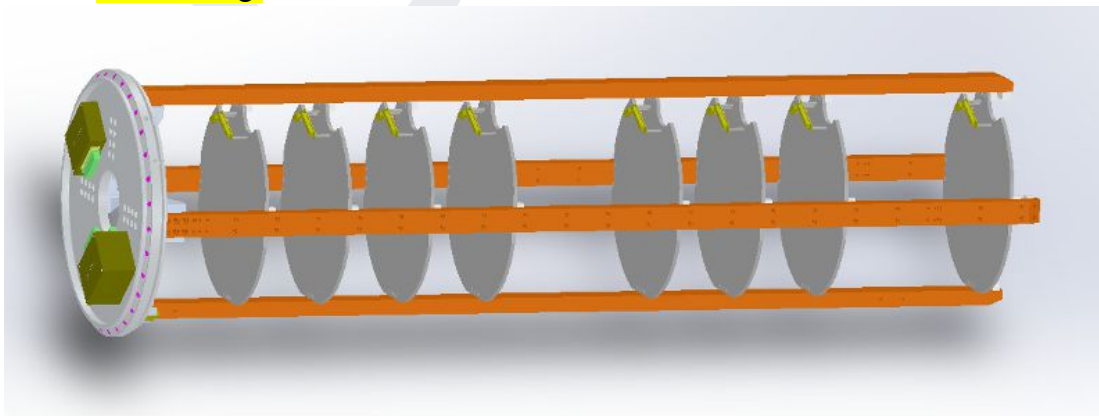


Figure 2-1a: RockSat-X Deck in Longeron Structure (Conceptual)



Figure 2-1b: RockSat-X Deck in Longeron Structure (Actual)

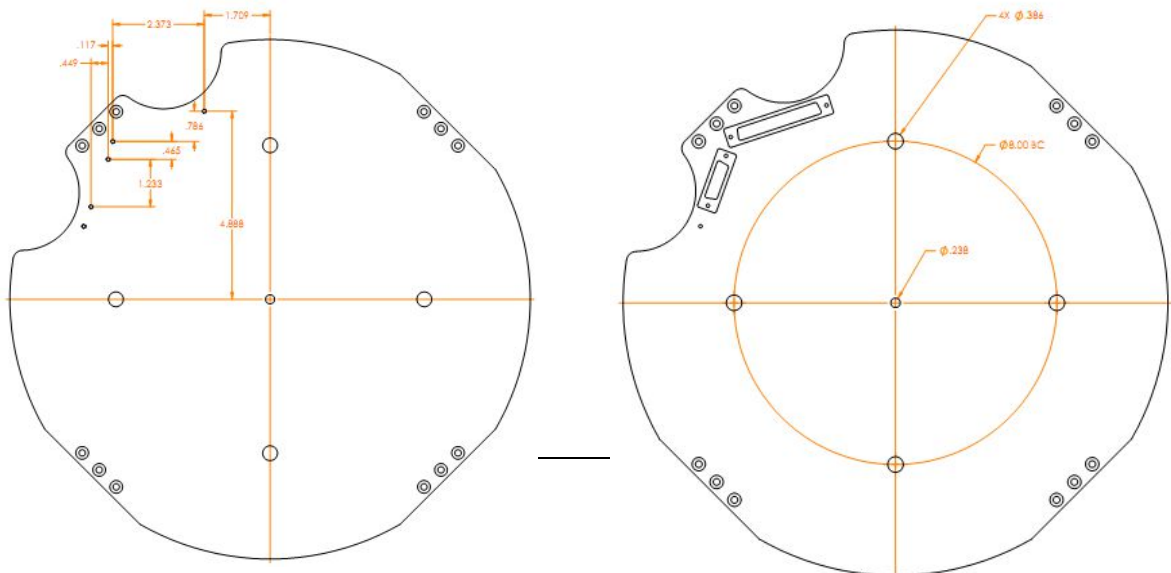


Figure 2-2: RockSat-X Deck Layout

The objective of the RockSat-X experiment deck is to give customers a design envelope to build around that will allow easy integration to any WFF rocket using the CarRoLL experiment section design. This standardized approach provides customers low cost access to space.

RockSat-X will have an ejectable skin (the skirt) that will fully expose experiments to the space environment at apogee. WFF will provide power and telemetry to each experiment deck. By providing these resources, experimenters can spend more time on experiment design and less on power and data storage systems.

3.0 ROCKET DESCRIPTION AND CAPABILITIES

This section covers key interfacing and launch vehicle capabilities that customers should be aware of for the design of their experiment.

3.1. RockSat-X General Capabilities Description

Each RockSat-X deck will be attached to the CarRoLL structure in a stacked configuration. This structure consists of longerons that span the entire length of the experiment section (Figure 2-1a&b and Figure 3-1). With 5 RockSat full experiment spaces (decks) in the aft and one full experiment space in the nosecone, the launch vehicle (Terrier-Improved Orion or Terrier-Improved Malamute) is estimated to reach an altitude of approximately 150 – 170 km, or approximately 100 miles.

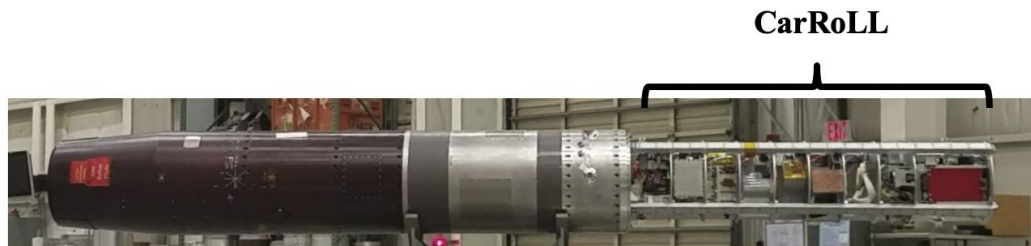


Figure 3-1: Payload Stack with CarRoLL Section

There will be a total of six full RockSat-X experiment spaces available for purchase. The five full spaces in the CarRoLL can be split into half for a total of up to 10 experiments. Each of the six full experiment spaces shall be provided with four timer controlled (4) power lines (TE) and associated ground wires that can be activated during flight at the experimenter's request. One (1) of these power connections will be redundant. Each full experiment space will also be provided with two (2) sets of power lines that can be activated prior to launch through the Ground Support Equipment (GSE) and as such have been dubbed GSE lines. It is highly recommended that main experiment activation occur through the GSE line. It is also required that any deployment actions not be triggered by GSE lines but by TE lines. Each full experiment section will have a 1 Amp Hour (Ah) battery available for the mission. Current draw on this battery is limited. Please see Figure 5-8. Customers will connect to power via the power and telemetry interface described further in Section 5.3.1. Please note that half experiment space customers will need to share these four TE and two GSE power lines as well as the 1 Ah battery with another half experiment space customer. The WFF RockSat-X Program Manager will coordinate these sharing arrangements.

Each full experiment space shall be provided with telemetry resources with access to ten (10) 0 – 5 Volts, 10-bit Analog to Digital (A/D) lines. Analog signals from 0 – 5 Volts will be digitized and streamed back to the ground station in real-time, which eliminates the need for on-board data storage. Additionally, each section will receive one (1) asynchronous line (SERIAL) at a 19,200 baud rate and a 16-bit parallel line (PARA). Customers shall output data via the power and telemetry interface described further in Section 5.3.1. More details on telemetry can be found in Section 5.3.2.3. Again, half space experiment sections will have to share these resources with another half space experimenter. The WFF RockSat-X Program Manager will coordinate these sharing arrangements.

The RockSat-X deck is circular in shape with a usable experiment space (design envelope) having a diameter of approximately 12 inches with a keep out area that is defined in detail in Section 5.2.2. Each full experiment space deck will have 10.75 inches of height (5.13 inches for half sections). Each full experiment space deck is allotted 30 ± 1 lbs (15 ± 0.5 for half sections) including the deck and power and telemetry interface connectors. All experiments shall weigh in at 30 ± 1 lbs (15 ± 0.5 for half sections). Experiments lighter than this shall provide their own ballast weights that are securely fastened to the deck to meet this weight requirement. Any violation of weight or volume requirements will result in the customer being removed from the flight. **Details on the deck for the nosecone are forthcoming.**

3.2. Rocket Key Performance Parameters

Below are the typical key performance parameters for the RockSat-X rocket. They are subject to change without notice.

Table 3-1: Key Performance Parameters

Key Performance Parameter	Value	Notes
Altitude (km)	~160 km	1,3,4
Spin Rate (Hz) at Burn-Out	~4.8 Hz at Malamute burn-out ~0 Hz at apogee	1,2,3,4
Maximum Ascent G-Load	25 G (Sustained) 50 G+ Impulses Possible	1,2
Rocket Sequence (Burn Timing)	5.2 second Terrier burn 12.2 second coast 11.7 second Malamute burn	1,3,4
Experiments Power Off	332 seconds	1,3,4
Splash Down (seconds)	882 seconds	1,3

Notes:

1. All parameters are subject to change, but all customers will be notified of any changes.
2. Data from Rosanova 41.092 RDM (2011)
3. Data from Rosanova 46.004 MRR (2012)
4. Data from Koehler 46.012 MRR (2015)

3.3. Flight Environment Conditions

3.3.1. G Loading

During ascent and descent experiments will experience both sustained and vibrational accelerations. Typical quasi-static G loads can reach 25 Gs. Experiments shall be designed to withstand at least 25 Gs of quasi-static loading in all three axes with possible impulses of approximately 50 Gs in the Z (longitudinal) axis. Three axes vibration testing will be conducted by WFF before flight. Vibration/environmental testing will be completed approximately 1 month prior to launch. The specifics of this test can be found in Appendix B. Key structural parts of any RockSat-X experiment shall not be made of 3D printed materials.

3.3.2. Flight Environment

After second stage burn-out, the skin and nose cone will be ejected exposing all experiments to the vacuum of space. Experiments will be exposed to hard vacuum and varying temperature extremes. The primary mode of heat transfer at apogee will be radiation as convection becomes non-existent in the vacuum

of space. The vacuum environment will also lead to outgassing. Requirements for design to account for thermal extremes and vacuum conditions are not being imposed, but these factors should be considered in design. Outgassing becomes particularly important for optical experiments located near high outgassing materials. Outgassing properties for most materials can be found at: <http://outgassing.nasa.gov/>.

3.4. Recovery

Unlike the standard RockSat-X Program, recovery will not be a part of GHOST. Thus, experiment teams are expected to use the telemetry system to its fullest capabilities to transmit their necessary experimental data. It is also possible for experiment teams to use a mobile ground station that they have designed and built to receive signals from an antenna they have included on their experiment. Another possible resource is the Iridium Network.

4.0 ORGANIZATIONAL RESPONSIBILITIES

4.1. Customer and WFF/ASP Responsibilities

Component and functional design responsibilities are listed below.

GHOST Experiment Customer

- Experiment and support system.
Support system includes:
 - Thermal system (if desired)
 - On-site tools and hardware for environmental testing and final integration
 - All environmental sensors (if desired)
 - Power regulation from nominal 28V±4V to any required experiment voltages
- Mechanical interface to RockSat-X deck
- Safety features for experiment-related hazards
- Power harness from experiment to power interface (minus connectors)
- Telemetry harness from experiment to telemetry interface (minus connectors)
- All required ground side data analysis equipment (computers not provided)

WFF/ASP

- Terrier-Improved Malemute rocket, range safety, launch support, and tracking
- One (1) RockSat-X deck with power and telemetry interface with associated power and telemetry harness connectors and stand-offs
- Environmental testing and integration onto full rocket

- GSE testing (experiment verification) during August integration and November launch
- Mission management support
- Program Management Support including:
 - Design Reviews
 - Testing Reviews
 - Documentation Reviews
 - Presentation of experiment to Wallops
 - Organizing and presenting experiment team requests

4.2. Ground Control

After the GHOST decks have been integrated onto the RockSat-X experiment section of the rocket prior to launch, the customer will have very limited access to the experiments. WFF will handle all activities pertaining to final experiment preparation, transportation (from WFF to ASP), and launch.

5.0 EXPERIMENT DESIGN & INTERFACE REQUIREMENTS

5.1. Experiment Physical Envelope, Mass, and Center of Gravity Requirements

The following subsections outline the physical requirements and constraints of the RockSat-X experiment deck.

5.1.1. Constraints On Experiment Types

The purpose or mission of an experiment is open to the customer. The customer shall design an experiment that by all standards (engineering and layperson) would be considered safe and practical. Experiments shall not put other experiments, the WFF payload as a whole, WFF/ASP employees, or the launch vehicle at risk. All experiments shall be formally selected before the customer can become a contender for flight. This formal selection will come after acceptance of the IFF by WFF in September. This formal selection does not mean the experiment has been selected for flight. That will come when the official manifest is made in September 2023. Experiments with stored energy devices, deployments, or separation systems will be subject to additional review and require hazardous procedure documentation approved and verified by WFF Management prior to integration and testing at WFF.

5.2. Mechanical

5.2.1. Physical Envelope

The customer is responsible for mounting their experiment to the experiment deck in a manner that will ensure its survival during flight. Finite Element Analysis (FEA) is highly recommended but not required. All experiments will

be environmentally tested at WFF prior to flight, which is the ultimate test of structural integrity.

Customer experiments must be designed for integration to fit within the 12-inch (30.48 cm) diameter by 10.75 inch (27.31 cm) high envelope (minus keep out area) already defined. Experiments can deploy booms and other mechanical devices once the skin has been ejected. Deployable or ejectable experiments introduce a new level of complexity and are subject to the more stringent design scrutiny from WFF. Release mechanisms such as compressed springs or Frangibolts must be approved prior to arrival at WFF and may require additional Hazardous Procedures to be approved by Wallops Ground Safety. These procedures must be submitted and approved by ISTR. All deployments require activation via a Timer Event (TE) line, and must deploy at a speed *less than* 1 inch per second (2.54 cm/s).

5.2.2. Mechanical Interface

All experiments shall be designed to mount to the RockSat-X deck. The deck design envelope is 12 inches (30.48 cm) in diameter.

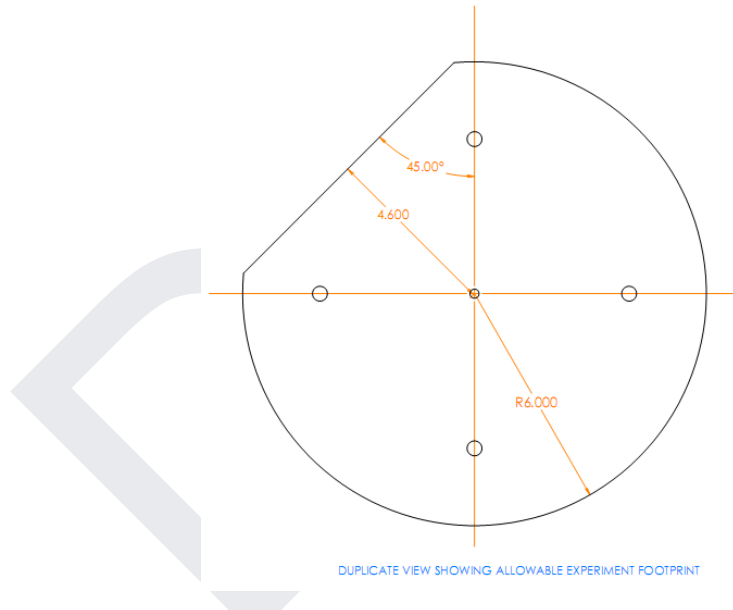


Figure 5-1: RockSat-X Experiment Design Space

Figure 5-1 shows the footprint of the space that customers can utilize for the experiment. The diameter is 12 inches (30.48 cm), and the excluded portion of the disk is a keep out area for the power and telemetry connectors and wire-ways to be discussed below. Any sufficient need to go into the keep out area shall be approved by WFF before teams can use this space. Customers may add holes to the plate but significant changes (more than 10% of material

removed) will need to be approved by WFF. Please note that the telemetry connector impedes slightly on the keep-out zone when mounted.

The power and telemetry connectors will be provided by WFF. In addition to providing the connectors, each experiment space will be provided with a set of stand-offs to mount the connectors to the deck. For design purposes, relevant dimensions on the location of the holes for connector mounting are summarized in Figure 5-2. Additionally, a SolidWorks model of the flight deck is available.

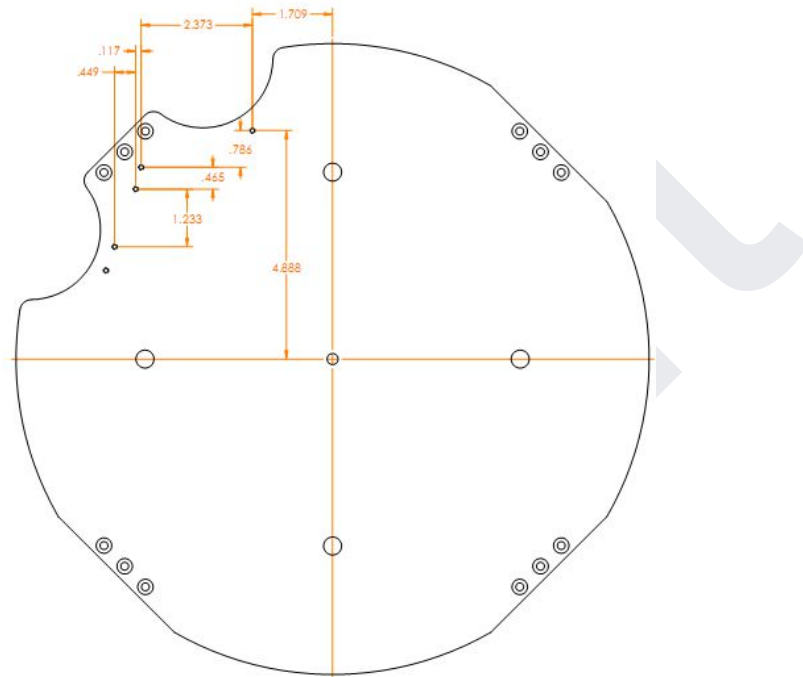


Figure 5-2: PT Connector Hole Dimensions

Customers have four options for mounting their experiment deck to the CarRoLL experiment section if using a full experiment space. These options are a bottom, bottom mid, middle, and upper mid mounting. The bottom mounting (BM) deck provides 10.75 inches (27.31 cm) of height, where the mid mount (MM) provides 5.62 inches (14.27 cm) below the deck and 5.13 inches (13.03 cm) above. Lower mid mount (LM) provides 2.82 inches (7.16 cm) below the deck and 7.93 inches (20.14 cm) above. The upper mid mount (UM) provides 8.44 inches (21.44 cm) below the deck and 2.31 inches (5.87 cm) above. In addition, half experiment space decks (HALF) may use up to 5.13 inches (13.03 cm) above their deck unless otherwise approved by WFF. A pictorial representation of these options are presented below in Figure 5-3. Half experiment space customers shall use the bottom mount location. Other locations will be considered on a case by case basis but shall be presented no

later than the PDR. All experiment decks shall countersink any fasteners on the underside of their decks. Nothing shall protrude from bottom of these decks to avoid interference issues with experiment decks that may be above or below these decks.

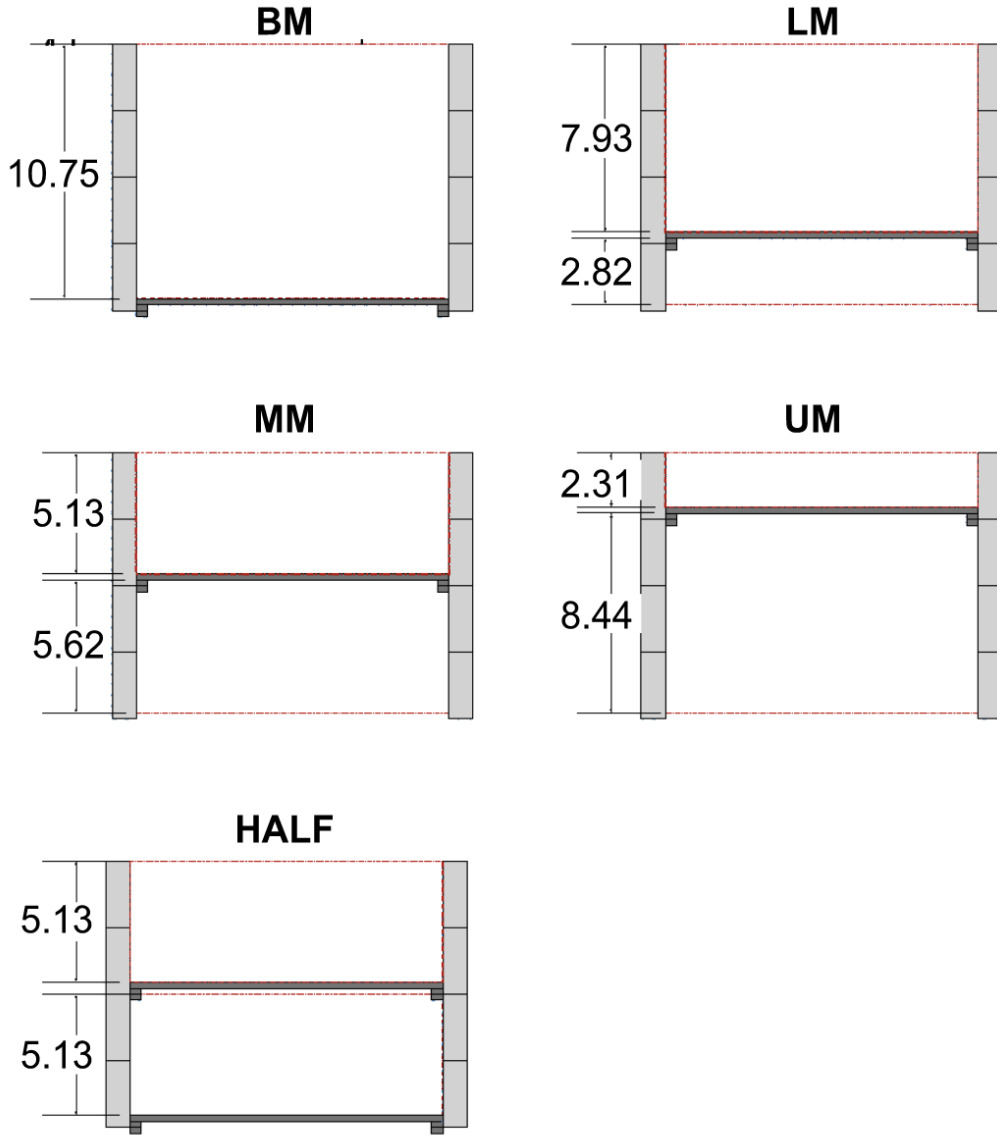


Figure 5-3: Deck Mounting Options (in inches)

The mounting blocks between the experiment deck and the longerons shall be mounted aft of the deck, regardless of which way the experiment may be facing. This should be taken into consideration when designing and building the experiment. A visual representation of this is laid out in Figure 5-4, in

which the nose of the rocket is to the left and the aft/motor mount is to the right.

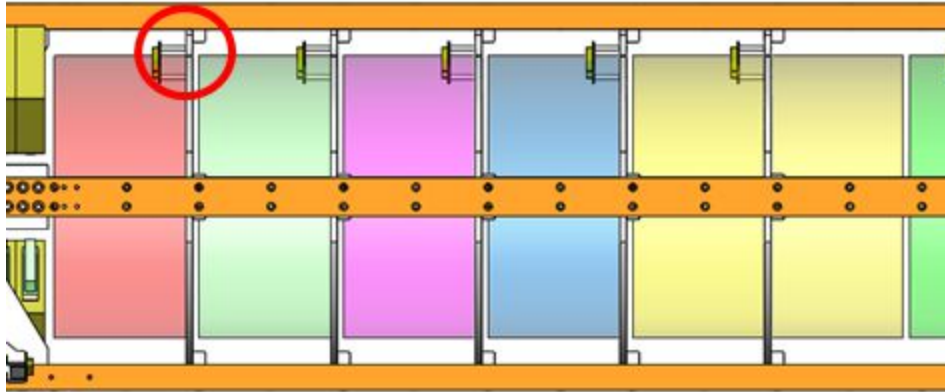


Figure 5-4: Mounting blocks aft of deck

5.2.3. Mass Properties

Each RockSat-X experiment (including deck and Power and Telemetry interface) shall be 30.0 ± 1.0 lbf (13.61 ± 0.23 kg). Fully assembled experiments will be weighed prior to WFF integration. Experiments not conforming to the weight constraints will be removed from the flight. Each RockSat-X shared experiment (including deck and Power and Telemetry interface) shall be 15.0 ± 0.5 lbf (6.80 ± 0.11 kg). All experiments shall weigh in at 30.0 ± 1.0 lbf (13.61 ± 0.23 kg) or 15.0 ± 0.5 (6.80 ± 0.11 kg) for half sections. Experiments lighter than this shall provide their own ballast weights that are securely fastened to the deck to meet this weight requirement. Any violation of weight or volume requirements will result in the customer being removed from the flight.

5.2.4. Center of Gravity

All experiments shall be designed to have a center of gravity (CG) that lies within a 1 inch square (2.54 cm) in the plane of the RockSat-X deck. The center of mass in the longitudinal direction is less important but shall be accounted for in design reviews. To ensure stable flight, WFF may require a moment of inertia (MOI) test prior launch. This test will confirm that the CG of the experiment falls within the said requirement. Experiments that do not meet WFF's CG requirements may be removed from the flight. WFF understands that this test at the experimenter level may be difficult to perform and will accept analytical models showing compliance to this requirement.

5.2.5. G Loading

Each experiment will experience extreme and varying G-loads during the course of flight. It is not atypical to see up to 25 Gs in the positive Z (longitudinal) direction during ascent and experience about +/- 10 Gs in the X and Y (lateral) axes. Experiments shall be designed to withstand at least 25 Gs of quasi-static loading in all three axes with possible impulses of approximately 50 Gs in the Z (longitudinal) axis. In the event of a parachute failure, there will be more extreme loading in all three axes.

5.2.6. Material Selection

When designing the structure for the experiment, materials with high resistance to stress corrosion cracking (SCC) are recommended. Materials that have worked well in the past have been aluminum (6061) and steel. Plastics or other petroleum-based materials shall be used sparingly. PLA/3D printed parts should not be used for key structural components.

5.2.7. Power and Telemetry (PT) Interface

The RockSat-X program utilizes a standard interface to deliver power from the rocket to the customer. Additionally, said interface provides a standard for passing telemetry from the customer to rocket. Each experiment team shall complete the Interface Control Documents (ICDs) for both Power and Telemetry as part of their CoDR, PDR, and CDR deliverables.

To keep this program low cost and low impact to WFF, a standard interface and number of power and telemetry lines was established for all experiment decks. The PT interface will mount to the RockSat-X experiment deck and will provide customer side and Wallops side connections. Using this standard will allow the use of an Electrical Ground Support Equipment (EGSE) suitcase. This suitcase will initially provide 28V ($\pm 4V$) to power lines and allow monitoring of the telemetry lines to verify functionality prior to final integration to the rocket. The supplied voltage will increase to 32V at T-180s to simulate the switch to internal battery power.

5.2.7.1. PT Interface Design

The customer side Power and Telemetry Interface consists of two (2) d-sub connectors that are provided by WFF. Each experiment deck will receive one (1) thirty-seven (37) pin d-sub connector for telemetry and one (1) fifteen (15) pin d-sub for power. These connectors and associated mounting hardware (stand-offs) will be mailed to final down selected customers after the team's 3rd payment has been received.

Figure 5-5 shows a representative thirty-seven (37) female connector and fifteen (15) pin male connector that will be mailed.

Draft



Figure 5-5: Telemetry (Top) and Power (Bottom) Connectors

Note that the pin numbers are engraved on the backside of the provided Cannon connector.

Once the appropriate connections have been made, it is the customer's responsibility to mount the d-sub connectors to the plate with the associated mounting hardware. The mounting hardware should be securely fastened, but not over torqued to avoid damage to the connectors, standoffs, or deck. The exact location of these connectors is described in Section 5.2.2. The pin-outs for both connectors are located in Sections 5.3.2 and 5.3.1.

5.2.8. Electrical Interface

The power interface for each experiment deck shall consist of a single fifteen (15) pin Cannon connector (Figure 5-5). Customers will connect all power and ground lines to the pins on the back side, and Wallops will mate directly with an opposite gender connector on the front side. This connector and associated mounting hardware will be provided by WFF after final down selections.

Each full experiment space shall receive the above said four (4) timer controlled power lines. Additionally, each full experiment space receives two (2) GSE activated power lines. The pin-out convention is given below in Table 5-1. Also shown in Figure 5-6.

Table 5-1: Power Interface Definition

Pin	Function
1	+28 Volts (GSE 1)
2	Timer Event R1 (TE-RA)
3	Timer Event R2 (TE-RB)
4	Timer Event 1 (TE-1)
5	GND
6	GND
7	GND
8	GND
9	+28 Volts (GSE 2)
10	Timer Event 2 (TE-2)
11	Timer Event 3 (TE-3)
12	GND
13	GND
14	GND
15	GND

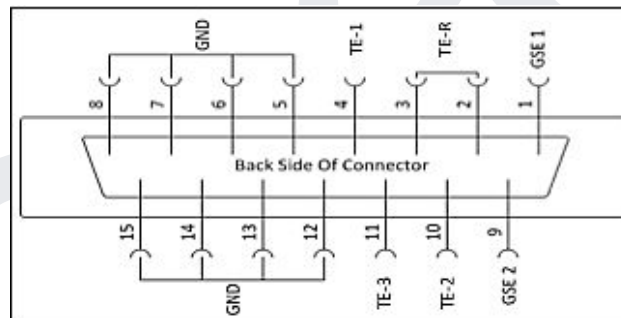


Figure 5-6: Power Connector Pinout

Pins 1 and 9 are GSE 1 and 2, respectively. These lines will become active at the customer specified T-X seconds prior to launch. T-X shall be less than 600 seconds but more than 180 seconds to prevent complications with the switch from external power to internal battery power. Pins 5-8 and 12-15 are experiment and Wallops ground. Customers can tie their experiment ground to all or any combination of these pins. Customers who are half experiment spaces will be assigned GSE and TE pins based on their experiment needs to avoid overlap of use by other half experiment space customers by WFF.

Pins 2 and 3 will be activated simultaneously for a customer specified activation time to provide redundancy. These lines will become active at the customer specified T+X seconds into launch. Pins 4, 10, and 11 are the non-redundant (TE) timer controlled power lines that will activate at independent times specified by the customer. These times shall occur after launch, as they are controlled by the launch timer.

5.2.8.1. Power Provided and Activation

The timed event lines (pins 2-4 and 10-11) can be activated at any time after the launch (T+X seconds) of the vehicle. The on-board timer controls the activation of these lines. These lines are characterized by three (3) states: on, dwell, and off. At a customer specified time (t_{on}) after launch, the line will switch from off (no power) to on for a customer specified dwell time, t_{dwell} . After t_{dwell} , the line will switch from on to off and will remain in this state for the remainder of the mission until t_{splash} . Figure 5-7 shows the timing diagram for the four (4) timer controlled power lines. The green times indicate those specified by the customer. The t_{dwell} cannot exceed the experiment power off time, which typically is before the predicted maximum reentry heating of the flight. For 2012, this time was T+346 seconds. For 2013, this time was T+337 seconds.

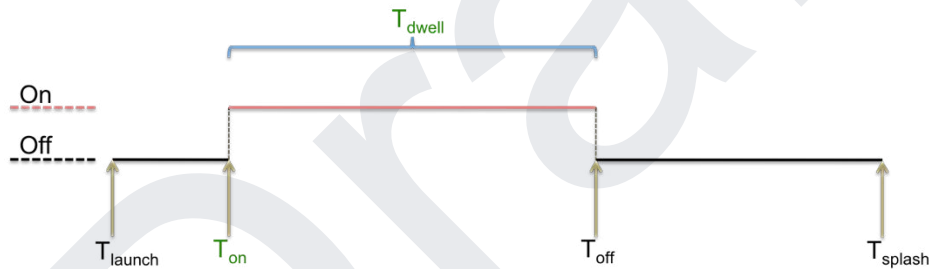


Figure 5-7: Timer Timing Diagram

Of the four power lines controlled by the timer, one (1) will be redundant. This line will have two dedicated timer events (occurring at the same time) and two independent solenoids for two levels of redundancy.

The fifth and sixth power lines (28V) are controlled by Wallops Ground Support Equipment (GSE), and can be activated up to six hundred (600) seconds (10 minutes) prior launch or as late as one hundred eighty (180) seconds (3 minutes) prior to launch. It is recommended that primary electronics be controlled through the GSE line with peripheral sensors and subsystems being activated through the above described timer lines. All deployments shall be powered by timer events. Additionally, Wallops will transfer power from your experiment by external power supply at ~28V to the internal battery which could be as high as 32.4V. It is important to design power conversion stages that can handle these transient voltages.

Wallops will activate the GSE lines during environmental and other testing on the rail prior to launch, which should be taken into consideration in electrical design. This means that your system will be turned on via GSE multiple times prior to launch and you will not have access to reset any systems. The provided power lines and timing are summarized in Table 5-2.

Table 5-2: Power Lines Provided

Type	QTY	Timing
Redundant (28V)	1	Customer specified, post launch (T+)
Non-redundant (28V)	3	Customer specified, post launch (T+)
Non-redundant GSE (28V)	2	Customer specified, pre-launch (T-)

Each full experiment space will be allotted a dedicated battery with 1 Ah of capacity. Additionally, current draw on the GSE lines and timed events will be limited as summarized in Figure 5-8. These limits will be enforced through the use of polyfuse switches on Wallops' power bus and EGSE. **NOTE: While the power system is capable of handling 3.75A per TE line, the maximum total current draw for any experiment space is limited to the 3.75A.**

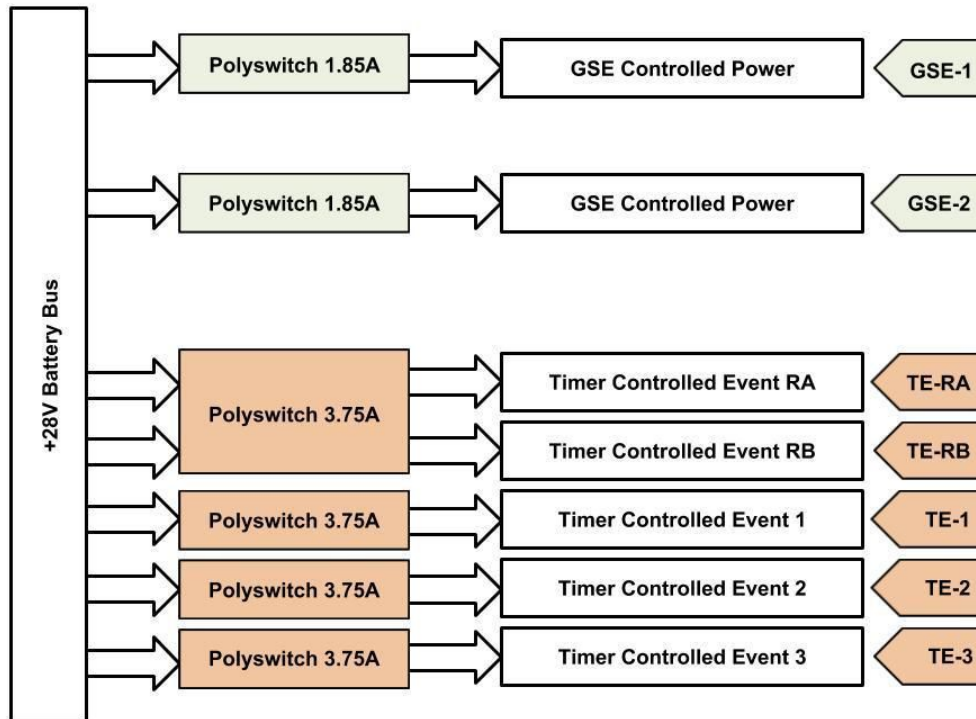


Figure 5-8: Current Limits

5.2.8.2. Independent Power Sources

Wallops Flight Facility shall provide the power for all experiments. In the event that an experiment needs a voltage greater than the provided 28V, the customer will be responsible for providing power. This power source must be cleared by both WFF, and a written, formal approval must be issued from the institution before the experiment can fly. Experiments utilizing high voltages must also conform to the requirements provided in Section 5.5. It is important that customers ensure that there is no voltage or current on their experiment deck or through any of their interface wires (power and telemetry) while inactive. Batteries and/or stored power sources shall be inhibited by either a GSE or TE line. Customers may use rechargeable lithium batteries, but rechargeable lithium ion batteries may not be recharged while the experiment is at WFF. Other types of rechargeable batteries may be used and recharged at WFF, such as NiMH. Non-rechargeable lithium ions are allowed. It is recommended that all experiments have their batteries approved by WFF before purchasing them. All rechargeable batteries that will require recharging at WFF shall have a UL listing on both the charger and the batteries. There are no exceptions to this requirement. Failure to follow this requirement will be cause for removal from the rocket. Real-time clocks and other devices requiring button cell batteries may be allowed but shall be presented no later than the PDR for WFF approval.

5.2.9. Telemetry Provided

Each RockSat-X full experiment space will be provided with ten (10) 10-bit 0 – 5V A/D lines. Customers must condition all sensor signals to 0-5V. These signals will be converted by Wallops to a 10-bit digital representation that will be sent down on the telemetry stream. These lines are high impedance into the A/D deck, so buffering the signals is not necessary. The A/D decks do not filter the data in any way; however, it is strongly recommended that each input be filtered appropriately to minimize undesired noise. The sample rate is fixed at 1 kHz.

In addition to the A/D lines, full experiment space customers will be provided with one (1) parallel line and one (1) asynchronous line. The parallel line will accept a 16-bit digital signal that will also be sampled according to the timing diagram in the auxiliary document: RS-X Telemetry ICD. Most customers use a parallel line to monitor status (on/off) of certain aspects of the mission. The asynchronous line will have a baud rate 19,200 bps.

Table 5-3: Telemetry Lines Provided

<i>Type</i>	<i>QTY</i>
10-Bit 0-5V A/D	10
Parallel (16 bit)	1
Asynchronous	1

5.2.9.1. Telemetry Interface

The telemetry interface for each experiment deck shall consist of a thirty-seven (37) pin Cannon connector (Figure 5-5). This connector and associated mounting hardware will be provided by WFF after 3rd payment has been received. The ten (10) A/D lines shall be conditioned to 0 – 5 volts and shall connect to pins 1 – 10 on the Cannon connector. Pins 11 – 16 will contain bits 1 – 6 of the parallel line with pin 11 being the Most Significant Bit (MSB). The final 10 bits shall be placed on pins 20 – 29, with 29 being the Least Significant Bit (LSB). Pin 30 is reserved for the parallel read strobe. The asynchronous connections shall be made on pins 32 and 33 for data to be transmitted and ground, respectively. Pins 18, 19, 36, and 37 shall be experiment ground, which will be tied into Wallops ground via the connector. Pins 17, 31, 34, and 35 will not be utilized (NC). This convention is summarized below in Table 5-4.

Table 5-4: Telemetry Interface Definition

Pin	Function	Pin	Function
1	Analog 1	20	Parallel Bit 7
2	Analog 2	21	Parallel Bit 8
3	Analog 3	22	Parallel Bit 9
4	Analog 4	23	Parallel Bit 10
5	Analog 5	24	Parallel Bit 11
6	Analog 6	25	Parallel Bit 12
7	Analog 7	26	Parallel Bit 13
8	Analog 8	27	Parallel Bit 14
9	Analog 9	28	Parallel Bit 15
10	Analog 10	29	Parallel Bit 16 (LSB)
11	Parallel Bit 1 (MSB)	30	Parallel Read Strobe
12	Parallel Bit 2	31	N/C
13	Parallel Bit 3	32	RS-232 Data (TP1)
14	Parallel Bit 4	33	RS-232 GND (TP2)
15	Parallel Bit 5	34	N/C
16	Parallel Bit 6	35	N/C
17	N/C	36	Ground
18	Ground	37	Ground
19	Ground		

Note that the pin numbers are engraved on the backside of the provided Cannon connector.

5.2.9.2. Asynchronous Framing and Baud Rates

Customers utilizing the asynchronous line are responsible for correctly framing data before sending it to the telemetry connector. Framing is easily accomplished through a Universal Asynchronous Receive Transmit (UART). Most COTS microcontrollers have this ability (however they may not condition voltage levels appropriately for RS-232, so a level shifter may be required). The serial link uses the RS-232 protocol, which is further explained in the auxiliary document: RS-X Telemetry ICD.

All customers shall use the 8-N-1 convention. 8 indicates that each frame consists of 8 data bits, N indicates that no parity bits are being used, and 1 indicates a single stop bit. The typical 8-N-1 frame is summarized in Figure 5-9.

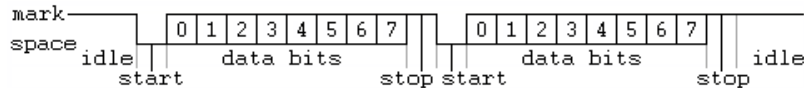


Figure 5-9: 8-N-1 Asynchronous Serial Framing

Source: www.wikipedia.com

The start bit is always a signal low followed by eight bits (0-7) of data, with a final stop bit at logic level high. A UART will complete all framing if implemented correctly. Customers can communicate over this serial connection at a baud rate of 19,200 bps.

Baud rate is NOT equal to data rate. 19,200 Baud implies that 19,200 characters per second can be communicated, where “characters” includes the required start and stop bits. For an 8-N-1 frame, 2 start/stop bits or characters are required per frame, which implies a 20% overhead (2 [start-stop bits]/10 total bits). Extrapolating this concept, a 19,200 Baud connection is capable of streaming 15,360 [0.8*19,200] bits of actual data per second.

5.4 High Voltage

All experiments using the provided 28V from WFF are strongly encouraged to conformal coat all electronics to protect against coronal discharge. All experiments utilizing voltages higher than 28 V shall conformal coat all boards. Experiments utilizing higher voltages must obtain the written permission of both Wallops Flight Facility.

5.5. Electrical Harnessing and Staking

All experiments shall harness wires with a nylon lacing tape or the equivalent. Wire harnesses that are excessively long should be staked to the structure to mitigate the risk of disconnects during flight. It is also highly recommended that all connectors and IC sockets be tied and staked in place using aerospace grade RTV (Such as Dow Corning 3145). Wallops Flight Facility payloads use Dow Corning products (734 and 736) for potting and electrical connection. These products can be purchased from McMaster Carr at: www.mcmaster.com

5.6. Radio Frequency Transmissions

All experiments utilizing RF systems will be required to fully detail these systems. This will be done by completing a Frequency Utilization Request (FUR) form and submitting it to WFF through the Program Manager at CDR. Approval of RF systems will be conducted by WFF to ensure that there will not be interference with necessary WFF payload systems. All RF systems shall be designed to activate after launch, and cannot be based on a GSE line, only a Timer Event line. No RF transmissions will be allowed on the launch pad. All RF systems shall be operational during the June testing trip for the WFF GPS Roll-out test. These RF systems shall be able to turn-on with a GSE line for this test only or be able to be manually turned off and on. Experiments with non-functional RF systems during the June testing trip will not be flown regardless of FUR form approval.

5.7. Summary of Key Constraints

Table 5-5: Summary of Key Constraints

Type	Quantitative Constraint
Physical Envelope	Cylindrical**: Diameter: ~12 inches (30.48 cm) minus keep out Height: ~10.75 inches (27.31 cm) ~5.13 inches (13.03 cm) for half This height does not include the height of the deck. ** Deployables and booms are permitted once skin has been ejected
Weight	Experiment deck shall be: Full experiment - 30±0.5 lbf (13.61 kg ± .23 kg) Shared experiment - 15±0.25 lbf (6.8 kg ± .11 kg) The deck and connectors weigh 3.41 lbs (1.54 kg)
Center of Gravity	Lies within a 1 inch (2.54 cm) square in the plane of the RockSat-X deck
Power and Telemetry	Telemetry Ten (10) 0 – 5V 10-bit A/D Lines One (1) parallel line One (1) asynchronous line Power One (1) redundant power line (28 ±4V) Three (3) non-redundant power lines (28 ±6V) Two (2) GSE power line (28 ±4V) 1 Ah capacity
High Voltage	All experiments utilizing higher voltage (>28V) shall conformal coat all electronics.

6.0 EXPERIMENT HARDWARE INTEGRATION

The customer shall deliver (via shipment to WFF) a complete, functional, and fully integrated experiment to WFF in August 2024. Prior to this delivery, a Visual Verification Check-in (VVC) shall be presented by the RockSat-X customer to WFF Management. The review shall demonstrate that the experiment meets all of the requirements of this document and is flight ready. If the experiment does not meet the specifications of this document or the expectations of WFF management, the customer will not be permitted to ship their experiment for integration and testing. All RockSat-X experiments will then be re-tested at WFF after shipment. If re-test is successful, the

experiment will be integrated and undergo environmental testing in mid-June. After environmental testing, experiments shall remain integrated at Wallops until November 2024. Customers will travel to the Andøya Space in Norway in November 2024 for final sequence testing and RBF procedures.

7.0 EXPERIMENT TEST REQUIREMENTS

Testing of the experiment shall be performed by the customer to ensure experiment functionality and survivability. All tests shall be documented and/or recorded for the testing reviews whose dates have been established in Section 5.0.

7.5. Structural Testing

The customer shall perform any testing that they see fit to ensure that their experiment will survive the launch environment. In addition to the testing completed by the customer, WFF will perform a three axes vibration test in June. It is highly recommended but not required that customers perform vibration testing prior to arriving at Wallops Flight Facility. Details on the vibration testing levels can be found in Appendix B.

7.6. Vacuum Testing

It is not required but highly recommended that the customer run a full mission simulation in a vacuum chamber.

7.7. Day in the Life Testing (DITL)

The customer is required to run and document at least two (2) full mission simulations to demonstrate functionality of the experiment. This test should consist of the experiment being operated on the bench as an integrated experiment for the entire mission life (less than 30 minutes). The results of these tests will be presented at the weekly teleconferences as indicated on the schedule.

7.8. Wallops Flight Facility Testing

August Integration and Environmental Testing

The August Integration and Environmental Testing (I&E) is the most important testing phase for RockSat-X experiments. This will be the closest to a true mission simulation that will be available. The experiments are installed onto the WFF experiment section and testing is conducted to ensure systems behave in a way that is safe and acceptable for flight. It is required that experiments be fully mechanically and electrically functional and active during the August testing. WFF will not allow or accept significant mechanical or electrical changes after the August testing has occurred. During all testing, experimenters should expect GSE and timer events to become active. The following tests will be conducted in August:

- Full electrical sequence
 - All systems will be turned on in accordance with GSE and TE specified timing.
 - Sequence testing will be done multiple times both before and after vibrational testing.
- Vibration
 - Full experiment stack will be tested on the vibration tables as described in Appendix B.
- Moment of inertia
- Spin balance
- Radio frequency interference (RFI)
 - Systems will be turned on and electrical noise and RF emissions will be detected and characterized.
 - The RF portion of your experiments shall be able to turn on and off either with a GSE line or a manual switch
- GPS Rollout
 - WFF will test the experiment GPS and telemetry systems fully.
 - Experiments with purposeful RF devices are required to be powered during this test and actively transmitting RF as it would be for flight.
 - The RF portion of your experiments shall be able to turn on and off either with a GSE line or a manual switch
- Skirt Separation
 - The experiment skirt separation using pyrotechnic devices will be tested for smooth operation.

A summary of the powered tests that will be completed at WFF during the August Testing and Integration week is available in Appendix D. Please note that any test may be repeated if WFF or RockSat-X PM deems it necessary. RockSat-X participants must be able to complete all testing in compliance with RockSat-X guidelines in order to launch. Experimenters are able to enable/disable inhibits in-between tests following documented and approved procedures.

November Integration and Launch

During the integration portion of launch, the following tests will be conducted:

- Full electrical sequence
 - All systems will be turned on in accordance with GSE and TE specified timing. This will occur multiple times
- RFI Test (if needed)

- GPS Rollout (if needed)
- Check balance
- Turn on, vertical, horizontal checks on the launch pad
 - Each system will have GSE power turned on multiple times prior to launch. Experiment design must be able to compensate for turning on with no ability to reset experiment.

The August launch date is dependent on many factors that can cause a launch to slip beyond the intended launch window. All launches have a launch window of 3-4 days. While the first day of the window is ideal, weather, boats in the impact area, issues with the launch vehicle, or other circumstances may cause a delay in the launch. In previous years, launches have been postponed a day in 2015, a month in 2012, and as much as seven months in 2014. For this reason, the RockSat-X program makes no promise of a launch on a specific date. Many launches do occur on time and without issue.

8.0 SELECTION PROCESS

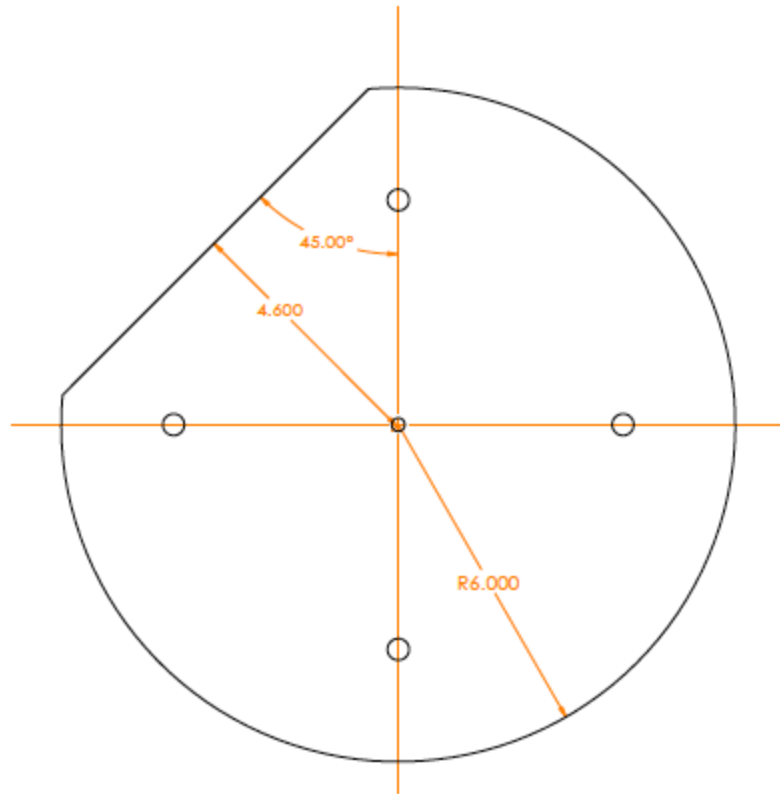
Any educational institution wanting to participate in RockSat-X shall submit the IFF in March 2023. The completion IFF is required to participate in GHOST and is due no later than March 30, 2023 at 5 PM MDT. The IFF can be found here. <https://tinyurl.com/ghost-iff> It is expected to take ~20 minutes to complete this form. Although required, submission of the IFF does not mean that your team has been selected for flight on the GHOST program. The IFF will be reviewed, and initial selections will be made by the end of mid April 2023. Initially selected candidates will be chosen based on responses to the questions on the IFF. Due to the limited experiment space on the RockSat launch vehicles, a down-selection process may be utilized after the successful completion of the RockSat Conceptual (CoDR) and Preliminary (PDR) design reviews. Each of these presentations will be reviewed and used to determine the flight worthiness of all initially selected candidates. If a team is down-selected, a full refund for their first payment will be issued minus a small processing fee. No later than September 2023, WFF will award flight opportunities (the flight manifest) to the GHOST experiments that are the most mature and ready to continue in the engineering process. Once a project has been selected, the customer's space has been reserved and no refunds will be issued for any reason; this includes but is not limited to failing to complete the experiment before launch or being removed from flight by either Wallops Flight Facility.

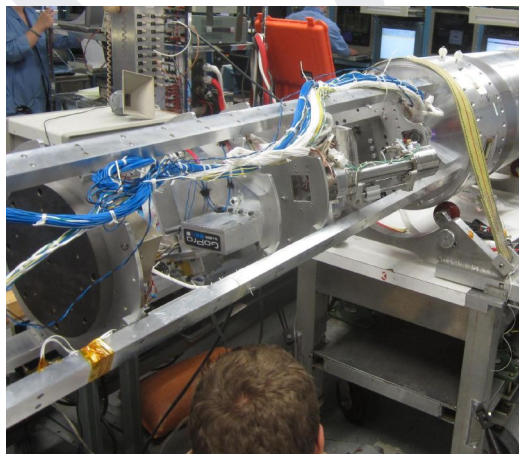
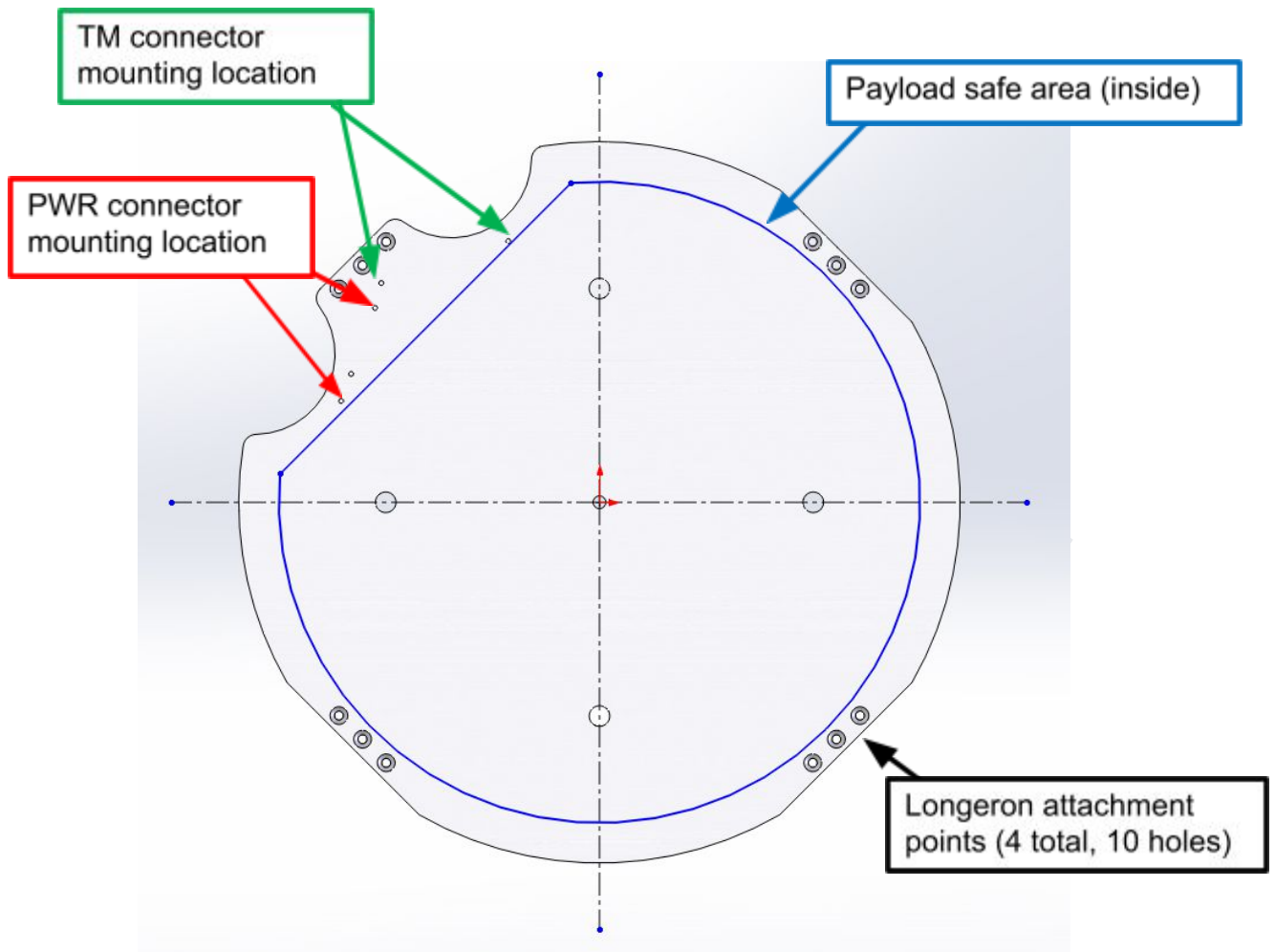
9.0 SCHEDULE

The following are key deadlines and reviews that the customer should be aware of and are subject to change.

Date	Milestone/Event
APR 17, 2023	IFF DUE
APR 24, 2023	GHOST Teams Selected/Notified
JUL 5-10, 2023	CoDR (Review)
AUG 16, 2023	1st Payment DUE
SEP 11-14, 2023	PDR (Review)
SEP 22, 2023	Down-Select Complete and Flight Manifest
NOV 13-17, 2023	CDR (Review)
NOV 29, 2023	2nd Payment DUE
JAN 22-26, 2024	STR (Review)
MAR 25-29, 2024	ISTR (Review)
APR 3, 2024	3rd Payment DUE
MAY 20-24, 2023	FMSR (Review)
MAY 2023	Optional ESA-PAC Symposium (Lucerne, Switzerland)
JUN 24-28, 2024	VVC (Review)
JUL 12, 2024	Ship Experiments to WFF
AUG 11-18, 2024	GHOST I&T Trip (WFF)
NOV 2024	GHOST Launch Trip (ASP)
JAN 17, 2025	GHOST Reports DUE

10.0 APPENDIX A: Mechanical Drawings/Interfaces





10.0 APPENDIX B: Environmental Testing Characteristics

** NOTE: The following specifications are based on the levels used on RockSat-C/RockOn. If other levels are to be used, this section will be revised as necessary.

Environmental Testing Characteristics:

Wallops Flight Facility's Environmental Test for the RockSat Program has two components: The Sine Test and the Random Test.

Sine Test:

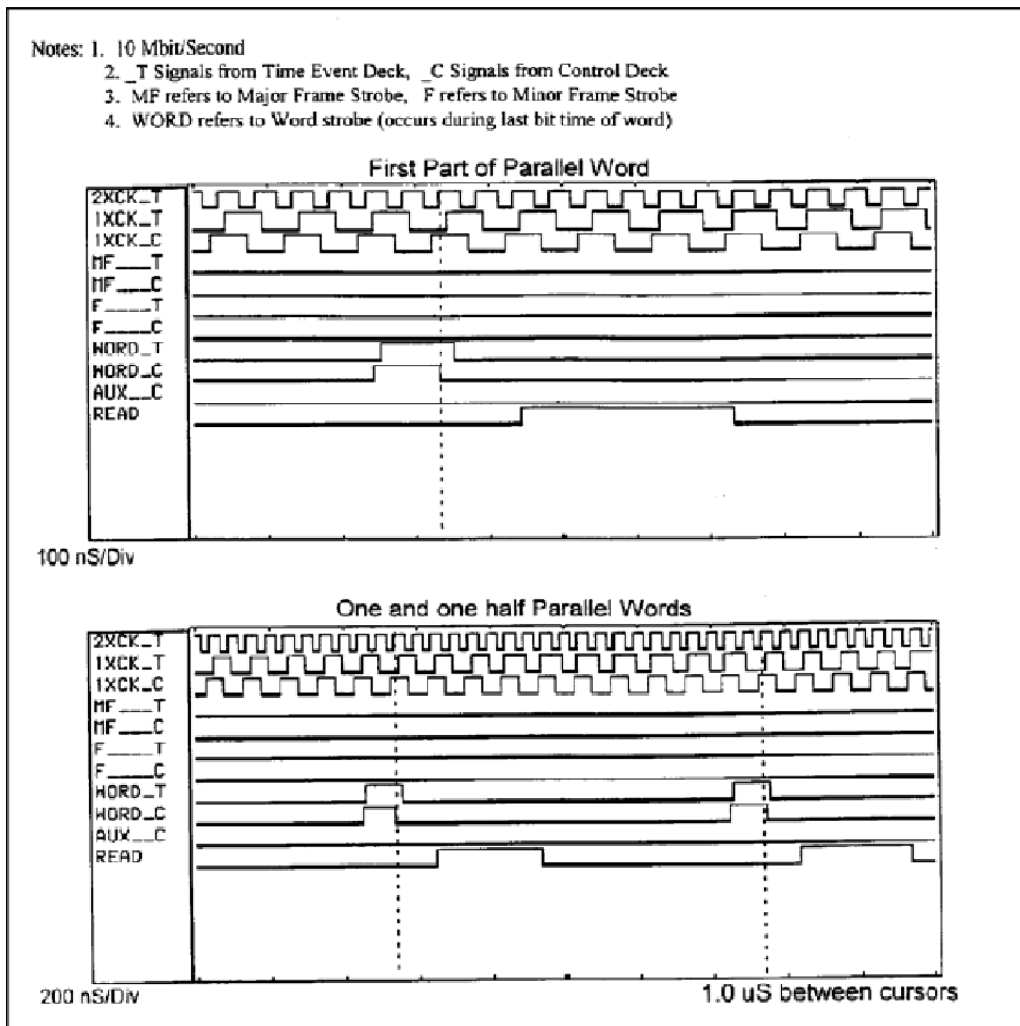
The Sine Test will vibrate the experiment along the thrust axis at no more than 3 in/s. These rates will occur between the frequencies of 10 and 144 Hz. The thrust axis will also see 7G from 144 to 2000 Hz. The sweep rate is 4 octaves per minute.

Random Test:

The random test will be completed in all three axes: thrust, lateral, and 90 degrees from lateral. The test will begin at lower levels and gradually increase to full level. Each axis will see 20 seconds at full level.

Thrust Full Level: 10 G_{rms} at 0.051 G^2/Hz from 20-2000 Hz
Lateral and Lateral 90 Full Level: 7.6 G_{rms} at 0.029 G^2/Hz from 20-2000 Hz

11.0 APPENDIX C: Supplemental Telemetry Specifics



12.0 APPENDIX D: Summary of August Testing Operations

Test	GSE Power	TE Power	TM Recorded	Notes
GSE Checkout	YES	YES	YES	<ul style="list-style-type: none"> • Uses mobile EGSE equipment prior to mechanical integration. • Weight and height recorded. • Testing monitors flight deck, power, and telemetry voltages for compliance. • Full Mission simulation. • Tests may be repeated if an issue arises or if RockSat-X PM has a need.
Sequence Test 1	YES	YES	YES	<ul style="list-style-type: none"> • Occurs at WFF F-10 ground station with experiment mounted to the rest of the WFF payload.
Sequence Test 2	YES	YES	YES	<ul style="list-style-type: none"> • First round of Pre-vibration full sequence tests. • Full mission simulations. • Tests may be repeated multiple times if an issue arises or WFF has a need.
Vibration Test	YES	NO	NO	<ul style="list-style-type: none"> • Experiment GSE lines powered during multiple phases of vibration test. System could be turned on for over 10 minutes multiple times.
Sequence Test 3	YES	YES	YES	<ul style="list-style-type: none"> • Second round of full sequence testing. • Full mission simulations.
Sequence Test 4	YES	YES	YES	<ul style="list-style-type: none"> • Tests may be repeated multiple times if an issue arises or WFF has a need.
GPS Rollout Test	YES	NO	NO	<ul style="list-style-type: none"> • System check to verify WFF payload RF communications. • All RF experiments must be operational during this time.

13.0 APPENDIX F: Summary of November Norway Testing & Launch Operations

Test	GSE Power	TE Power	TM Recorded	Notes
GSE Checkout	YES	YES	YES	<ul style="list-style-type: none"> Weight and height recorded. Testing monitors flight deck, power, and telemetry voltages for compliance. Full Mission simulation. Test may be repeated if an issue arises or RockSat-XN PM has a need.
Sequence Test 1	YES	YES	YES	<ul style="list-style-type: none"> Occurs at ASP ground station with experiment mounted to the rest of the WFF payload.
Sequence Test 2	YES	YES	YES	<ul style="list-style-type: none"> Full mission simulations. Tests may be repeated multiple times if an issue arises or WFF/ASP has a need.