

# NarSha - Korea's First Spaceborne Methane Monitoring Mission Using a Hyperspectral Microsatellite Constellation

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**Abstract**— Methane (CH<sub>4</sub>) is a significant driver of climate change, responsible for approximately 30% of global warming since industrialization and exhibiting a global warming potential over 80 times greater than that of carbon dioxide (CO<sub>2</sub>) on a 20-year timescale. Despite its impact, methane emissions remain highly uncertain due to systematic underreporting, particularly in the oil and gas sector. In 2020, South Korea emitted approximately 27 million tons of methane, accounting for 4.1% of national greenhouse gas emissions. The agriculture, waste, and energy sectors contributed 97% of these emissions, with fugitive emissions from energy operations exceeding 70%. To achieve carbon neutrality by 2050, South Korea must reduce methane emissions by 40% relative to 2018 levels, requiring accurate and policy-relevant monitoring. To address limitations in existing satellite observations, including insufficient coverage over offshore and high-latitude regions, the NarSha project was initiated in 2023 as South Korea's first spaceborne methane monitoring mission. The project aims to deploy a microsatellite constellation that provides high-resolution methane measurements to complement ground-based inventories and support local governments in implementing greenhouse gas reduction policies. By improving emission quantification and identifying discrepancies across sectors, NarSha enables evidence-based decision-making at regional and municipal levels. Led by Nara Space in collaboration with Seoul National University's Climate Laboratory, and international partners like Scanway Space, the project plans to launch the Korean Methane Monitoring Microsatellite (K3M) in 2026. K3M will detect methane emission rates as low as 100 kg/h and deliver concentration products within four weeks using a short-wave infrared hyperspectral imager with sub-1 nm spectral resolution and ground sampling distance below 50 m. Integrated on a 16U CubeSat platform with precise attitude control, AI-enabled processing, and high-speed X-band communication, the system will enhance methane transparency and support climate mitigation efforts.

**Keywords**— Methane Monitoring, Constellation, Hyperspectral Imager

## I. INTRODUCTION

In response to the escalating climate crisis, the Global Methane Pledge (GMP) was established during COP26 to catalyze international efforts toward a 30% reduction in methane (CH<sub>4</sub>) emissions by 2030. Methane is a critical driver of anthropogenic radiative forcing, contributing approximately 30% of observed global warming since the industrial era. On a per-molecule basis, CH<sub>4</sub> possesses a

Global Warming Potential (GWP) exceeding 80 times that of carbon dioxide (CO<sub>2</sub>) over a 20-year horizon [1,2]. Despite its significance, a substantial discrepancy exists between reported inventories and empirical observations. Within the petroleum and natural gas sectors, bottom-up emission estimates may be understated by as much as 70–80%, underscoring the urgent requirement for independent Measurement, Reporting, and Verification (MRV) enabled by satellite and geospatial technologies [3].

As the world's 10th largest economy and 9th largest greenhouse gas (GHG) emitter as of 2021, South Korea faces rigorous decarbonization requirements. In 2020, national CH<sub>4</sub> emissions reached 27 million tons, representing 4.1% of the total GHG profile. While agriculture, waste, and energy sectors account for 97% of these emissions, leakage within the energy infrastructure alone constitutes 71% of the CH<sub>4</sub> total. To align with its commitment to achieve carbon neutrality by 2050, South Korea has mandated a 40% reduction in CH<sub>4</sub> relative to 2018 levels [4]. However, the current reliance on ground-based inventories lacks the spatial granularity required for precise source quantification. Addressing these observational gaps—particularly in equatorial, maritime, and high-latitude production zones—is essential for robust policy implementation [5,6].

Regulatory frameworks are increasingly integrating top-down satellite data to enhance transparency. The U.S. Environmental Protection Agency (EPA) recently strengthened its Greenhouse Gas Reporting Program (GHGRP) through the 2022 Inflation Reduction Act, which introduced the first federal methane fee for facilities exceeding specific emission thresholds. These developments transition satellite remote sensing from a research tool to a primary instrument for regulatory enforcement and international climate accounting [7].

The current landscape of spaceborne GHG monitoring can be categorized into four distinct observational scales:

- **Global-Scale:** Systems such as GOSAT, OCO-2/3, and TROPOMI provide coarse-resolution (>7 km) flux estimates suitable for continental and basin-scale analysis.
- **Local-Scale:** Missions including GHGSat and MethaneSAT offer regional quantification with

enhanced temporal frequency for industrial sector attribution.

- **Facility-Scale:** High-resolution spectrometers like Carbon Mapper’s Tanager and NASA’s EMIT target “super-emitters,” detecting point sources as low as 50–100 kg/h [8].
- **Next-Generation:** Emerging missions, such as CO2M and the Korean NarSha initiative, aim to provide the high-resolution coverage necessary for comprehensive MRV frameworks.

This study details the development of the NarSha project, South Korea’s inaugural spaceborne initiative dedicated to methane monitoring. The project involves a collaborative effort between Nara Space, Seoul National University, and Scanway S.A. to deploy the Korean Methane Monitoring Microsatellite (K3M), scheduled for launch in 2026.

The K3M platform is a hyperspectral microsatellite designed for facility-scale detection. Operating from a 500 km sun-synchronous orbit, the payload utilizes a hyperspectral imager optimized for the Shortwave Infrared (SWIR) absorption band (1625–1670 nm). The instrument achieves sub-nanometer spectral resolution with a Ground Sampling Distance (GSD) of approximately 25 m and a swath width exceeding 10 km. By integrating spaceborne K3M data with terrestrial sensor networks, the NarSha mission aims to significantly enhance the precision and spatial coverage of methane quantification. Figure 1 shows the concept of the NarSha mission.



Fig. 1. Illustration of the NarSha mission concept

## II. MISSION DESIGN

### A. Mission Objectives

The NarSha mission aims to strengthen domestic and international methane mitigation strategies by providing high-resolution spaceborne detection capabilities. The mission is defined by the following core objectives:

- **Sensitivity and Spectral Precision:** Detect CH<sub>4</sub> point sources of >100 kg/h utilizing SWIR hyperspectral retrievals with a spectral resolution of < 1 nm.
- **Temporal Resolution:** Maintain a 12-satellite constellation to achieve daily revisit frequencies over designated Regions of Interest (ROI).
- **Data Latency and Product Delivery:** Provide processed Level 2–4 data products, including concentration maps and emission rate estimates, within a four-week latency period.

- **Inventory Harmonization:** Facilitate the reconciliation of satellite-derived methane estimates with traditional ground-based emission inventories.

To facilitate effective GHG monitoring at the facility scale, detection thresholds must be maintained below several hundred kg/h of CH<sub>4</sub> [6]. The relationship between retrieval precision, spectral resolution, and signal-to-noise ratio (SNR) is detailed in Figure 2. Established benchmarks indicate that an emission rate of 1000 kg/h corresponds to a 600 ppb enhancement [9]; consequently, linear error analysis suggests that a 100 kg/h detection threshold requires a retrieval precision of better than 60 ppb [10]. This study adopts a conservative precision requirement of 50 ppb. To meet this specification, the optical payload and microsatellite system are designed to achieve an SNR of 150 with a spectral resolution of 0.6 nm.

### B. Concept of Operations

The mission's lifecycle, from orbital injection to end-of-life disposal, is illustrated in the Concept of Operations (ConOps) in Figure 4. Following separation from the launch vehicle, the satellite executes a sequence of automated tasks: deployment of solar arrays and antennae, detumbling maneuvers, and the transmission of status beacons. Initial commissioning is conducted via ground-based telecommands to verify subsystem integrity.

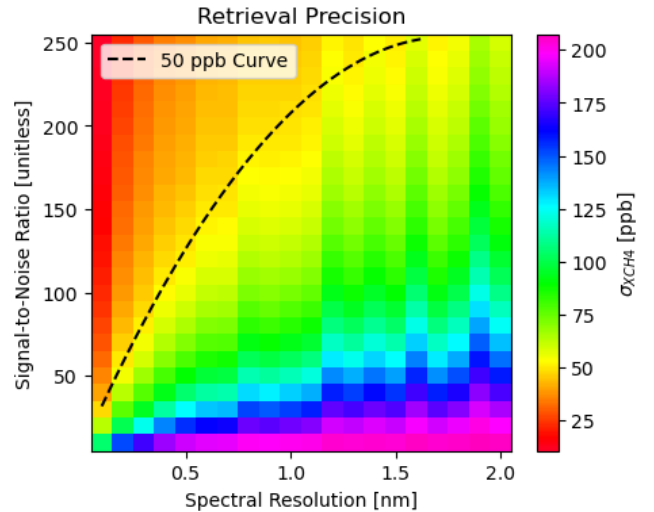


Fig. 2. Relation between spectral resolution and signal-to-noise ratio according to the retrieval precision

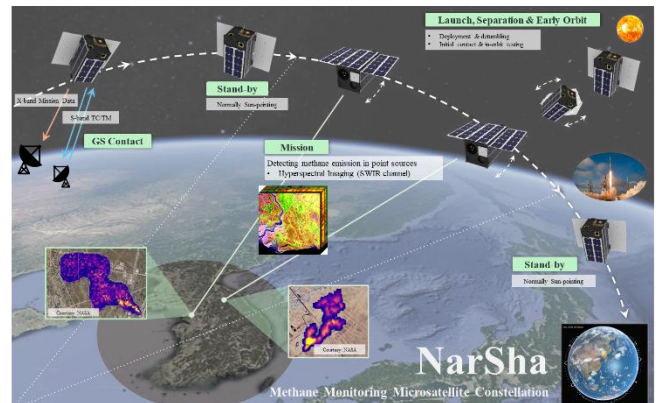


Fig. 3. Illustration of the concept of the operations

During nominal operations, the satellite maintains a Sun-pointing orientation to optimize power generation and battery charging. Telemetry and telecommand are facilitated via S-band communication through a global ground station (GS) network. High-volume mission data downlinks utilize X-band communication, with the capacity for scalability through additional GS contacts as required.

The mission mode is divided into three distinct sub-modes, selected based on the Solar Zenith Angle (SZA) and target characteristics to maximize the SNR:

- **Target Forward Motion Compensation (FMC) Mode:** Employed when the SZA is below 60 degrees. This mode enhances the SNR by reducing the satellite's ground speed to as low as 5% of its nominal ground track speed, effectively increasing integration time over the target.
- **Offshore Glint Mode:** Specifically utilized for marine observations. This mode is activated when the Viewing Zenith Angle (VZA) aligns closely with the SZA to capture specular reflections from the ocean surface.
- **Nadir Mode:** A standard strip-imaging configuration activated when the SZA is less than 10 degrees. This mode is primarily intended for detecting high-magnitude "super-emitters" and conducting routine on-orbit calibration of the optical payload.

### C. Constellation Architecture

To fulfill the stated mission objectives, the NarSha constellation will scale to 12 microsattellites by 2028. The inaugural deployment is scheduled for 2026 with the launch of the K3M. The constellation architecture utilizes a hybrid orbital strategy, integrating both Sun-Synchronous Orbits (SSO) and Mid-Inclined Orbits (MIO) at altitudes ranging from 500 to 600 km. As detailed in Table I, this dual-orbit approach is designed to optimize both temporal revisit frequency and spatial observation completeness. By leveraging 12 operational units, the constellation is projected to achieve a detection completeness of 90% or greater for intermittent CH<sub>4</sub> sources within a four-week window [6].

A primary advantage of this hybrid configuration is its resilience to seasonal variations. As illustrated in Figure 4, the synergy between SSO and MIO ensures consistent and uniform data collection throughout the year. Specifically, during periods characterized by a high SZA, the MIO components effectively bridge the observational gaps inherent in standard SSO coverage. This ensures that the mission maintains high-fidelity monitoring capabilities regardless of temporal or seasonal constraints.

TABLE I. CONSTELLATION DESIGN PARAMETERS

Parameter	Description
Orbit type	Sun-synchronous (SSO) and mid-inclined (MIO)
Altitude	500-600 km
Total # of satellites	12
# of orbital planes	4 (2 of SSOs, 2 of MIOs)
# of satellites per plane	4 @SSO, 2 @ MIO
Local time (SSO only)	10:30 and 13:30

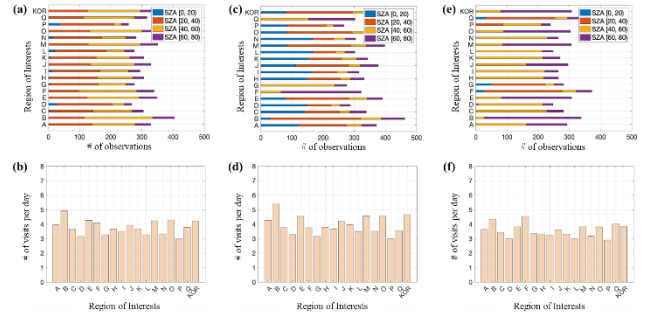


Fig. 4. Constellation revisit analysis according to the seasons (a, b: spring; c, d: summer, e, f: winter)

### III. MICROSATELLITE SYSTEM

Built as a 16U CubeSat, the K3M architecture integrates two optical instruments alongside a 4U-sized avionics subsystem. The mission's hyperspectral SWIR channel is optimized to resolve methane absorption features, whereas the auxiliary VNIR imager serves to enhance data quality through cloud masking and target verification. A summary of the microsattellite's technical parameters is presented in Table II, with the system's structural layout illustrated in Figure 5.

The K3M electrical interface architecture, depicted in Figure 8, utilizes CAN bus and RS-422/485 protocols for robust intra-subsystem communication. Payload command and control are managed via UART, while high-speed mission data transfer is facilitated by a LVDS link directly coupled to the X-band transmitter to ensure high-throughput telemetry.

TABLE II. SPECIFICATIONS OF THE K3M MICROSATELLITE

Contents	Performance
Lifetime	>3 yrs
Orbit	500-600 km (SSO & MIO)
Detection threshold	>100 kg/h
Data availability	L1, L2, & L4
Data delivery	<4 weeks/image
Spectrum	SWIR (CH <sub>4</sub> , 1625-1670 nm) VNIR (480 <sup>±15</sup> nm, 545 <sup>±15</sup> nm, 660 <sup>±15</sup> nm, 840 <sup>±30</sup> nm)
Spectral resolution	0.3 nm (SWIR, 150 channels)
SWIR SNR	>150 (albedo 0.2 & SZA 60°)
Ground sampling distance@500 km	50 m (SWIR & 2×binning) 12.5 m (VNIR)
Swath width	>10 km x 10 km
On-board processing	Data compression, cloud-detection & masking
Pointing accuracy	<+/-0.02 deg (3σ)
Off-nadir pointing	<+/-30 deg
Power generation	>80 Wh (EOL, sun-pointing)
Battery capacity	>150 Wh (EOL, 8s2p)
Data interface	CAN bus, RS-422/485
Data downlink	<150 Mbps (120 GB storage)

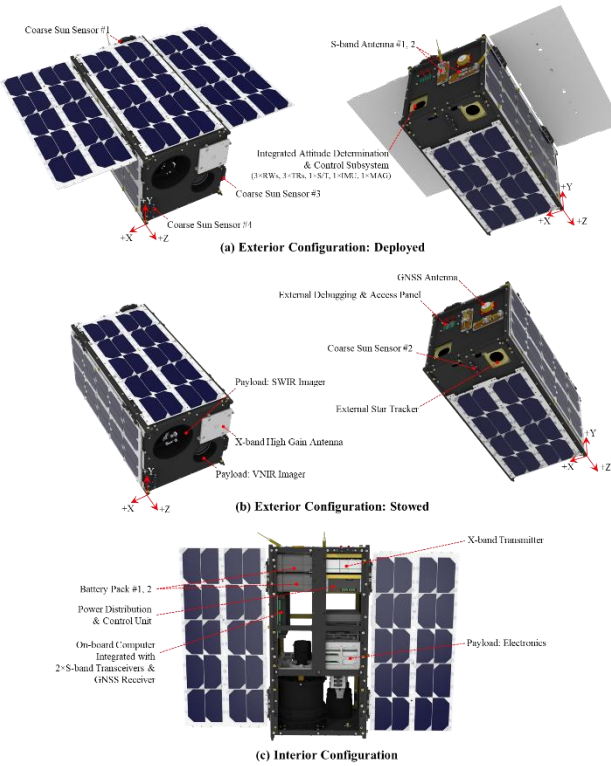


Fig. 5. Exterior and interior configurations of the K3M microsatellite

### A. Optical Payload

The onboard optical system comprises two sensors: a SWIR hyperspectral imager for methane monitoring and a VNIR imager for target identification. Both instruments feature a field of view exceeding 10 km x 10 km, making them well-suited for observing localized emitters.

To ensure precise methane detection, the SWIR imager provides high spectral resolution ( $\sim 0.3$  nm across 150 bands) and a Ground Sample Distance (GSD) of 25 m, which can be binned to 50 m. Architecturally, it utilizes a Ritchey–Chrétien (R–C) telescope paired with a diffraction grating and slit to disperse light into a continuous spectrum, ensuring a high SNR as shown in Figure 6. The sensor is designed to simultaneously capture spatial and spectral data along separate axes.

The VNIR imager focuses on target geolocation and cloud detection. By employing a butcher’s block filter, it captures RGB and NIR bands. From a 500 km orbital altitude, this instrument maintains a 16.25 km swath width and a GSD of 12.5 m.

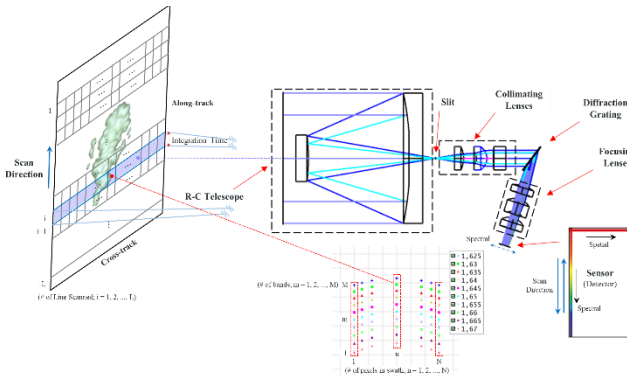


Fig. 6. SWIR hyperspectral imaging concept using a diffraction grating

Both imaging systems are linked to a GPU-accelerated edge-computing platform that enables data compression, cloud detection, and masking. These onboard processing capabilities are designed to optimize efficiency across the entire satellite constellation. Furthermore, an Active Thermal Control System (ATCS) provides the precise temperature regulation over the optics necessary to maintain and enhance superior image quality.

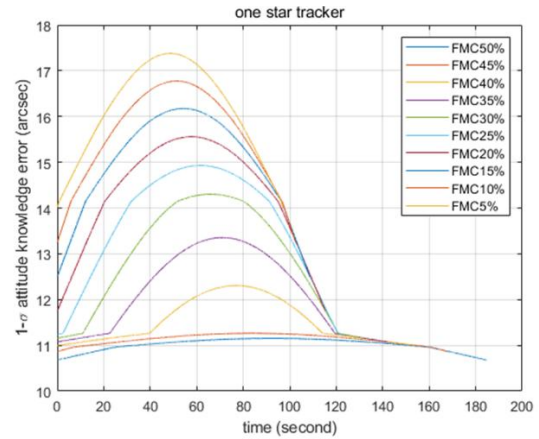
### B. Bus

The satellite bus comprises flight-proven architecture with essential avionics—including the on-board computer (OBC), power distribution unit (PCDU), and attitude control system (ADCS)—and is specifically engineered to provide the high-precision stability required for superior image quality.

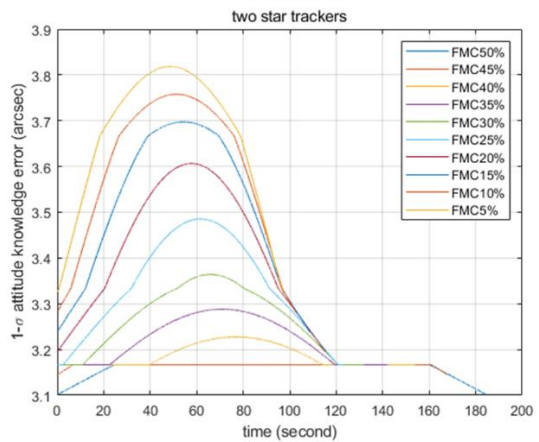
To maintain a high modulation transfer function (MTF), the system limits attitude jitter to less than 0.003 degrees, utilizing dual star trackers to keep knowledge error within 10 arcseconds during imaging maneuvers as shown in Figure 7.

The electrical power subsystem delivers up to 80 W to the payload and uses high-efficiency solar panels to generate over 50 Wh per orbit, ensuring that the battery depth of discharge remains under 30% even during intensive mission schedules.

Communications are managed by a high-performance OBC that integrates a GNSS receiver and dual S-band transceivers for reliable command and telemetry, while a high-speed X-band transmitter facilitates mission data downlinks with a robust link margin exceeding 6 dB.



(a) Single Star Tracker in -Y-axis



(b) Dual Star Trackers in -Z & Y-axis

Fig. 7. Attitude knowledge errors according to the star trackers’ configuration

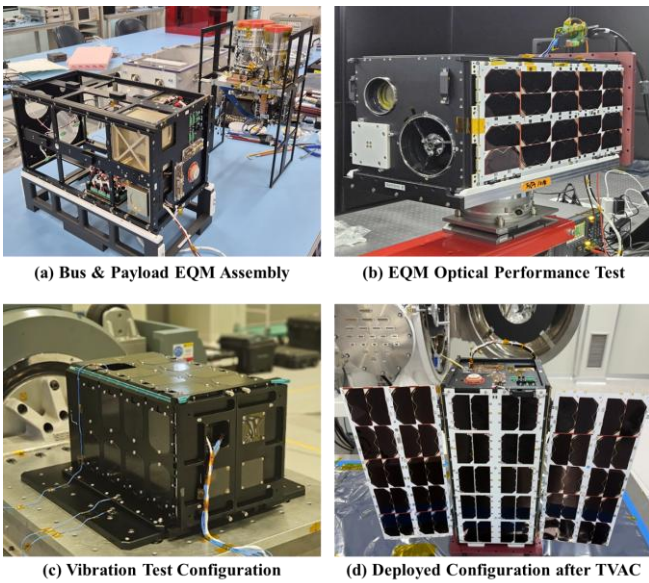


Fig. 8. Photos during the assembly, integration, and test campaign

#### IV. ASSEMBLY, INTEGRATION, AND VERIFICATION

To minimize development costs while maintaining system fidelity, the Payload Engineering Model (EM) and bus Qualification Model (QM) were integrated into a single Engineering-Qualification Model (EQM). This integrated system underwent optical performance testing both before and after a series of qualification-level environmental trials, including vibration and thermal vacuum tests, with the Assembly, Integration, and Testing (AIT) campaigns illustrated in Figure 8.

An airborne test campaign was conducted to verify the payload's end-to-end data processing chain. Figure 9 illustrates the initial results, including methane absorption peak detection and plume flow estimation derived from signal intensity.

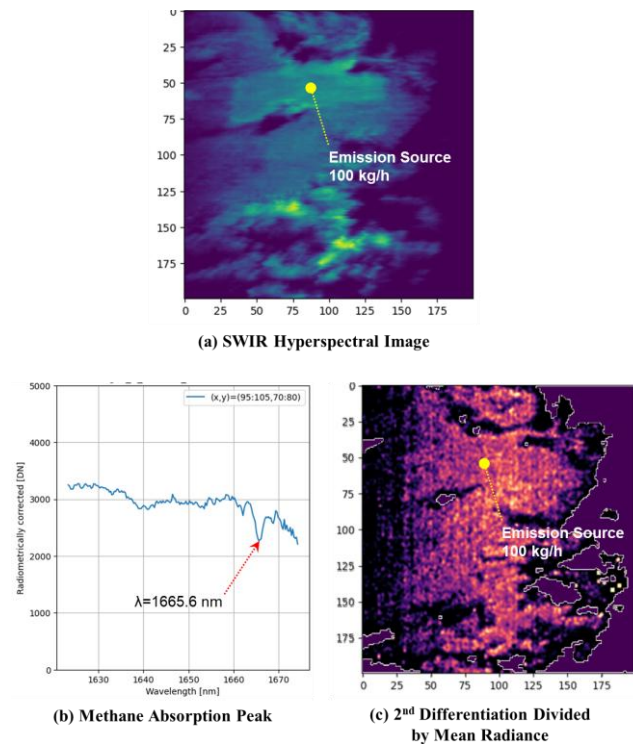


Fig. 9. Payload EM airborne test result – very first light and analysis

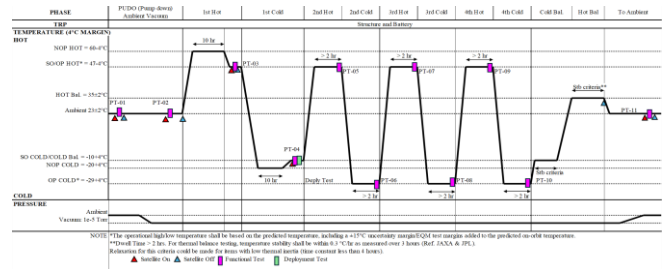


Fig. 10. TVAC test profile for the EQM

A random vibration test was performed in accordance with the qualification levels and acceptance criteria defined in the SpaceX Falcon 9 Rideshare Payload User's Guide [11]. Acceleration responses on the payload mounting plate were recorded using accelerometers to validate and correlate the structural simulation results.

Thermal vacuum and cycling (TVAC) testing consisted of one non-operational cycle and three operational cycles. During the cold soak phase, the deployment of the S-band antenna and solar panels was successfully verified. Throughout the operational cycles, the long-term performance of the hardware and flight software was evaluated. Finally, a thermal balance test was performed to correlate thermal interfaces and heat transfer characteristics with the analytical thermal model, with the test profiles illustrated in Figure 10.

To evaluate MTF stability throughout the vibration and TVAC campaigns, edge and relative edge response tests were conducted for the VNIR and SWIR imagers, respectively. Neither instrument exhibited significant degradation, confirming the optical integrity of the payload. These performance results successfully validated the robustness of the structural and thermal designs.

#### V. CONCLUSION

This paper presents the NarSha project, a methane-monitoring microsatellite mission centered on identifying and quantifying point-source emissions via a 16U CubeSat platform and a hyperspectral optical payload. While the mission maintains a global scope, it specifically addresses the carbon-intensive industrial landscape of South Korea and the broader Asia-Pacific region. To ensure high temporal resolution, a constellation of 12 or more satellites is planned.

A key validation of this asset-level approach is the pioneering adoption by South Korea's Gyeonggi Province, which is utilizing Nara Space's satellite platforms to establish the nation's first local government-led constellation. Given that Gyeonggi represents the third-highest greenhouse gas emissions in the country—with the second-highest growth rate over the last decade—this regional constellation (comprising one optical and two greenhouse gas satellites) will monitor dense industrial zones and carbon-neutral pilot complexes. This initiative provides a scalable blueprint for how regional authorities can leverage microsatellite data to support urban management, drive carbon reduction policies, and enhance global methane transparency.

Currently, the project is moving through its final development phases. Following the validation of the SWIR hyperspectral imager via airborne tests and the integration of the Engineering-Qualification Model (EQM), the first flight models (FM) are now under development with a scheduled launch set for Q4 2026.

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