NorSat-TD: How a Versatile Microsatellite Platform Can Enable Many In-Orbit-Demonstration Payloads

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ABSTRACT

The NorSat-TD mission is the next generation satellite in a series of Automatic Identification of Ships (AIS) missions built by the Space Flight Laboratory (SFL) for the Norwegian Space Agency (NOSA). In addition to the primary payload, namely an advanced AIS signal receiver, this mission also carries five diverse In-Orbit-Demonstration (IOD) payloads: a space-based VHF Data Exchange System (VDES), an electric propulsion module, a laser downlink terminal, a Precise Positioning Payload (PPP), and a miniature laser retroreflector. All six of the payloads on-board are substantially different from one another, and each has a unique set of accommodation and operational requirements. Not only can each payload support multiple experiments by itself, an extended set of experiments combining the capabilities of multiple payloads has also been proposed.

This paper will describe how a small generic microsatellite platform, measuring only 40 cm x 30 cm x 30 cm and weighing around 30 kg, was adapted to host these primary and secondary payloads. The unique requirements of each payload, its accommodation within the bus, and the associated experiments will be discussed. Mission planning and operational considerations will also be presented.

1 INTRODUCTION

Originally conceived as an AIS-only mission, the scope of NorSat-TD grew rapidly during the early phases of the program to include a number of In-Orbit Demonstration (IOD) payloads. Following a call for proposals to its partners, the Norwegian Space Agency (NOSA) selected a number of candidate payloads to be included onboard this satellite. Now, with partners spanning from Norway, Canada, France, The Netherlands, and Italy, the NorSat-TD mission grew from a single-user, single purpose satellite to a multinational collaboration consisting of an operational mission with experimental components.

The change in scope not only necessitated more volume and higher power generation than could be provided by the platform originally selected for this mission, but also brought with it a plethora of other challenges associated with the accommodation of multiple diverse payloads. SFL's DEFIANT platform was selected due to its versatility and capabilities, and was successfully adapted to meet the mission's needs. The NorSat-TD satellite is shown in the deployed and stowed states in Figure 1. Payload components are highlighted in Figure 2.

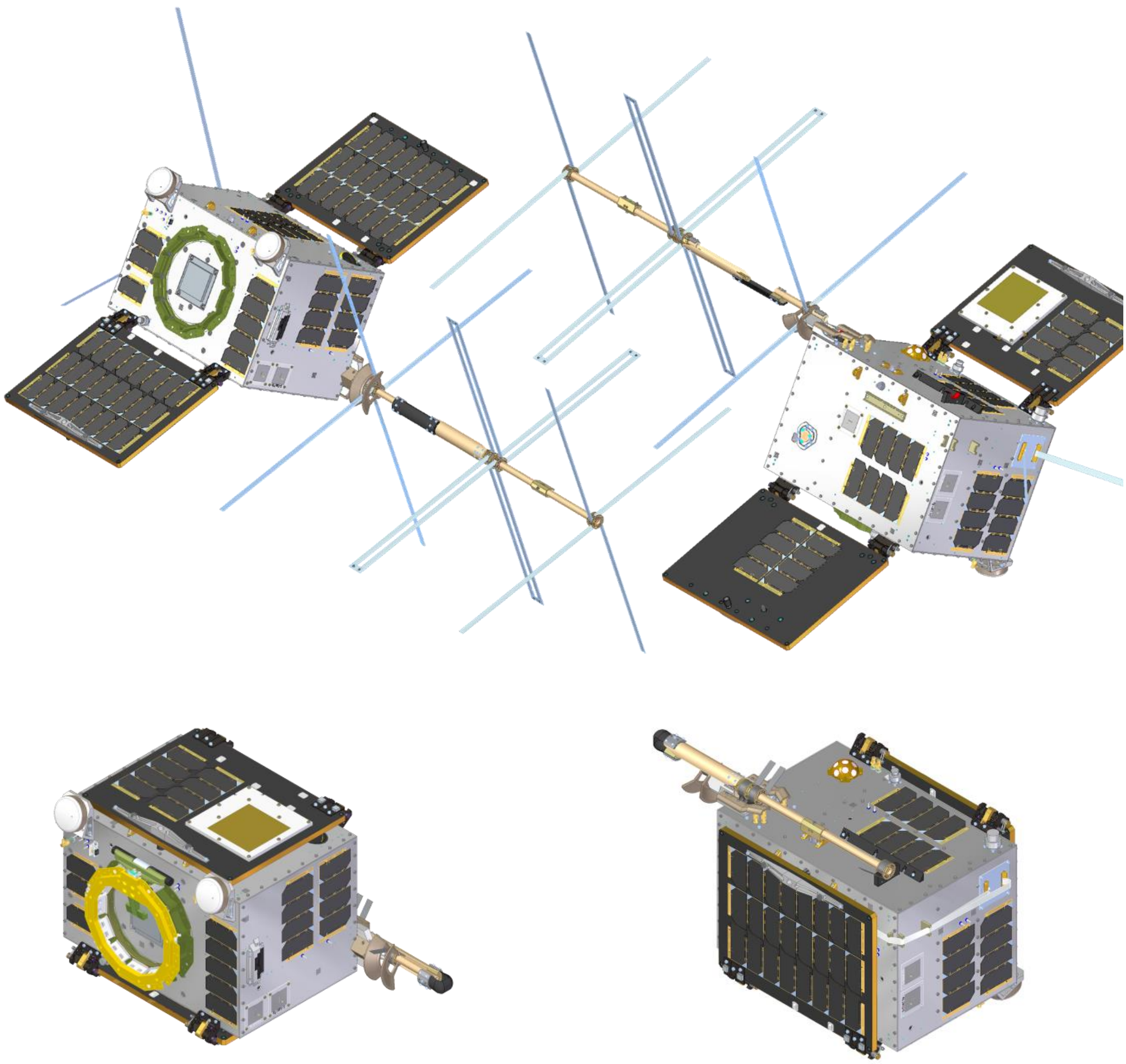

Figure 1: Upper: NorSat-TD deployed; Lower: NorSat-TD stowed

2 PAYLOADS

A brief overview of primary and experimental payloads is given below.

2.1 AIS and ISM Receiver

The primary payload of NorSat-TD is the ASR c50 AIS receiver from Kongsberg Seatex (KSX). This fifth-generation AIS receiver builds on the heritage of prior models which have flown on past SFL satellites for NOSA. The AIS payload fulfils the operational aspect of the NorSat-TD mission.

Quarter-wave monopole antennas are connected to two independent channels of the ASR c50 for detection of AIS signals. The two antennas are oriented orthogonally with respect to one another to allow for the effective reception of AIS signals in any spacecraft attitude, and despite the varying geometry between the source and receiving antennas as the satellite travels in its orbit. The two monopoles are stowed for launch and deployed by command following separation from the launch vehicle.

A third, general-purpose channel of the ASR c50 is configured for reception in the UHF ISM band, and will be used for detection of Internet of Things (IoT) signals. This channel is fed by an SFL-designed stacked patch antenna, which achieves moderate gain over a wide bandwidth. In order to efficiently utilize the satellite's external surface area, the antenna is mounted to the backside of one of the deployable solar arrays.

2.2 Space VDES

The VHF Data Exchange System (VDES) payload on NorSat-TD builds on the highly successful VDES payload flown on the NorSat-2 satellite. This system allows for efficient high-speed two-way data exchange between satellites, ships, and ground terminals. The upgraded payload implements a new power efficient transmitter with an expanded frequency range, capable of supporting the new frequency bands proposed in WRC-19. The transceiver is designed and built by Kongsberg Seatex for Space Norway.

The VDES payload uses a deployable three-element VHF Yagi antenna, originally designed by SFL for and successfully demonstrated on the NorSat-2 mission. Minor enhancements and modifications were performed to the antenna for compatibility with the DEFIANT platform, on which NorSat-TD is based. A miniature Visual Inspection Camera (mVIC) onboard the satellite will be used to confirm the successful deployment of the antenna. mVIC consists of three wide-angle cameras, which together capture all 12 segments of the antenna within their field of view.

A high-speed S-band receiver operating with a data rate of 1 Mbit/s is also included on the satellite to support the VDES payload. The receiver will be used to efficiently upload data to the satellite using an S-band ground station for further dissemination to ships via the VDES payload.

2.3 Electric Propulsion

NorSat-TD will carry the ThrustMe NPT30-I2, 1.5U electric propulsion system, which will be used for orbit maintenance and experimental maneuvering. This propulsion system is based on girded ion thruster technology, and includes the ion thruster, power supply, propellant tank, and feed system, in a single tightly-integrated package. The solid Iodine propellant makes this propulsion system inherently safe for storage, transportation and handling, and avoids other challenges such as dealing with fuel slosh.

2.4 Laser Downlink Terminal

CubeCAT is a compact, high performance, direct-to-Earth laser communications terminal for CubeSats and small satellites. It is developed by TNO in partnership with AAC Hyperion. The NorSat-TD variant, known as SmallCAT, adds vibration isolators to CubeCAT to help mitigate launch loads. NorSat-TD will be used to validate the SmallCAT payload as well as optical ground stations around the world.

As the SmallCAT payload requires attitude determination and control accuracy much higher than any of the other payloads, a star tracker is included on NorSat-TD specifically for it.

2.5 Precise Positioning Payload

The SpaceStar Precise Positioning Payload, provide by Fugro, will demonstrate sub-decimeter position determination of NorSat-TD. It will do so in real-time by augmenting the output of the bus' GNSS receiver with updates and corrections received from Fugro's network through geostationary satellites. The target for the SpaceStar experiment is to demonstrate real-time on-board positioning accuracy higher than 10 cm RMS (3D), and velocity accuracy higher than 5 mm/s RMS.

The payload consists of two primary components: the computational unit implemented in a software-defined radio (SDR), and an active L-band antenna.

2.6 Laser Retroreflector

The final payload on NorSat-TD is uCORA, a miniature laser retroreflector mounted on the exterior of the satellite bus. This completely passive device requires no power or data interfaces. It is used to track the satellite using laser ranging stations on Earth, and will be used to augment those experiments which require precise knowledge of the satellite's location in orbit. uCORA is contributed by the National Institute of Nuclear Physics (INFN) of Italy.

3 CONCEPT OF OPERATIONS

The NorSat-TD mission has an operational component consisting of the collection of AIS data, and an experimental component in which various aspects of the payloads are demonstrated. To facilitate mission analysis, and to overcome conflicting requirements between the payloads, operations of the satellite are split into use cases. Each use case defines which payloads are operational, the attitude profile of the satellite, and the modes of other bus components. On orbit, the satellite will cycle through the use cases, operating in each use case for a duration of one week before moving to the next. This time-sharing scheme will allow equal opportunity for each payload provider to perform their experiments, while also overcoming incompatibilities between the payloads themselves. The operational component, namely collection of AIS data, is carried out continuously in parallel with the experimental payloads.

Five use cases have been defined and analyzed to start, however additional ones can be added if extended experiments which don't fit within the existing use cases are identified. The five use cases are logically mapped to the five active payloads, namely the AIS & ISM receiver, VDES, Precise Position Payload, Propulsion, and Optical Downlink. The laser retroreflective is a passive payload, and can be ranged by optical ground stations any time the satellite is in a favourable attitude. Therefore, no dedicated use case is created for it. Table 1 summarized the state of each payload in each use cases.

Table 1: NorSat-TD use cases

	Use Cases				
	AIS & UHF	VDES	Precise Positioning	Propulsion	Optical Downlink
ADCS mode	Three-axis control				
ASR c50	**ON**	**ON**	**ON**	**ON**	**ON**
VDES	**OFF**	**ON**	**OFF**	**OFF**	**OFF**
SpaceStar	**OFF**	**OFF**	**ON**	**OPTIONAL**	**OFF**
NPT30-I2	**OFF**	**OFF**	**OFF**	**ON**	**OFF**
SmallCAT	**OFF**	**OFF**	**OFF**	**OFF**	**ON**
uCORA	Ranging possible depending on attitude				

4 EXPERIMENTS

Table 2 lists all of the experiments currently planned for the NorSat-TD mission. Some of these experiments are centered around a single payload, while others leverage complimentary functions of multiple payloads to achieve more elaborate experiments.

Table 2: NorSat-TD in-orbit demonstrations and experiments

	Experiment	Participants	Description	Use Case(s)
1	AIS	KSX	Collect Automatic Identification System (AIS) messages from high-performance AIS/IoT receiver.	AIS & UHF
2	UHF/IoT characterization	KSX	Characterize the 800-900 MHz UHF/IoT frequency environment in the Arctic for low-power LoRa and Sigfox terminals with a CubeSat receiver.	AIS & UHF
3	VDES AIS rebroadcast	Space Norway	Collect and rebroadcast local AIS messages to vessels in the area of interest and compare to NorSat-2 performance.	VDES
4	VDES receive and transmit	Space Norway	Perform two-way VHF Data Exchange maritime communications, demonstrating new VDE-SAT terminal.	VDES
5	VDES pseudo-constellation	NOSA, Space Norway, CNES	StatSat in cooperation with Space Norway and CNES will plan and execute changes to the orbit of NorSat-TD to place it in an optimized position relative to NorSat-2. This will allow a demonstration of the VDES service from a two-satellite constellation. As NorSat-2 is without propulsion it is required that NorSat-TD	Propulsion, VDES

			move from its initial orbit to a practically attainable orbit relative to NorSat-2.	
6	VDES ranging	Space Norway	Demonstrate VDES enabled maritime navigation and GNSS integrity monitoring through distribution of Precision Timing for UTC and pseudo-ranging.	VDES
7	SpaceStar demonstration	Fugro	Verify sub-decimeter augmented GPS positioning in real-time with a CubeSat receiver. Especially relevant is the demonstration of SpaceStar performance near the poles, where visibility to the GEO belt based L-band corrections are interrupted.	Precise Positioning
8	SpaceStar SLR verification	Fugro, CNES, ASI, INFN	The Italian provided uCORA satellite laser ranging retroreflector will be used to verify at the millimetre level the performance of the SpaceStar payload. CNES will gather observations from four international SLR stations at TNO, Matera, MeO Grasse, and Svalbard to perform accurate satellite positioning, and verify against the solution provided by SpaceStar.	Precise Positioning + uCORA
9	Thruster characterization	ThrustMe	ThrustMe will lead this experiment to characterize the performance of the Iodine-fueled gridded ion thruster.	Propulsion
10	Thruster maximum	NOSA, ThrustMe, CNES	The AIS receiver will be temporarily powered off to free up power resources, to be used for determining the maximum performance capabilities of the thruster and the DEFIANT bus.	Propulsion, less ASR c50
11	Optical downlink characterization	TNO	Demonstration of robust optical laser communications with an experimental CubeSat terminal via the transmission of a pre-defined bit stream to characterize link quality.	Optical Downlink
12	Optical downlink multi-optical ground station	TNO, FFI, KSAT, CNES, ASI	Perform optical laser communication with multiple ground stations from TNO, FFI, KSAT, CNES, Italy. This effort will be led and organized by TNO and will demonstrate that the SmallCAT terminal can operate with a diversity of optical ground stations.	Optical Downlink
13	Space Situational Awareness	CNES, ASI, NOSA	Collect SLR measurements from SLR stations and generate satellite ephemeris. Perform collision prediction, followed by collision avoidance maneuvers using the on-board propulsion system. Develop and verify safe methods for the planning, command, and verification of maneuvering in LEO.	Propulsion + uCORA

14	Thruster RF characterization	CNES, Space Norway, KSX, Fugro, ThrustMe	CNES will study the interaction of the electric thruster plasma cloud on incident signals in the RF bands: GNSS (1.64 GHz), L, S (2GHz), UHF (900MHz), VHF (150 MHz). The characterization of the RF environment in vacuum is only possible on orbit. The many varied antennas on NorSat-TD act as E-field probes; short duration, high-rate sampling from the AIS, VDES, SpaceStar, and bus receivers will be performed to investigate thruster impact on a wide range of frequency bands.	Propulsion + other payloads

5 MECHANICAL LAYOUT

The NorSat-TD satellite is built on SFL's generic DEFIANT platform. This platform lands itself especially well for this mission, as it provides ample payload volume, and a high degree of flexibility in payload placement.

Internally, the DEFIANT platform is divided into four volumes. One volume, the avionics bay, houses the power system, battery pack, and on-board computers. The second volume, the interstitial bay, houses up to four reaction wheels and optionally a chemical or electric propulsion system. A third volume, the radio bay, is dedicated to radio equipment, but also offers some space for payloads. The fourth and final volume, the payload bay, is fully dedicated to payloads. On the outside of the bus, a large surface area is available for external payloads and payload apertures. The rectangular prism shaped payload bay is positioned such that five of its six faces can accommodate aperture cut-outs. Large, flat payloads can also be mounted on the deployable solar arrays.

The separated internal volumes and multitude of unoccupied external surfaces allow payloads to be placed in optimal locations, considering their desired EMI environment, mechanical loads environment, orientation with respect to Earth or space, and with respect to other payloads and platform components. The NorSat-TD payloads and their supporting equipment generally fall into two categories: those that should point towards the Earth, and those that should point to space away from the Earth. Thus, the satellite is bisected into a nadir facing half, and a zenith facing half, and payloads are placed accordingly.

Placement of each of the six payloads is shown in Figure 2, and described further in the following sections. The requirements and rationale dictating these placements are also discussed.

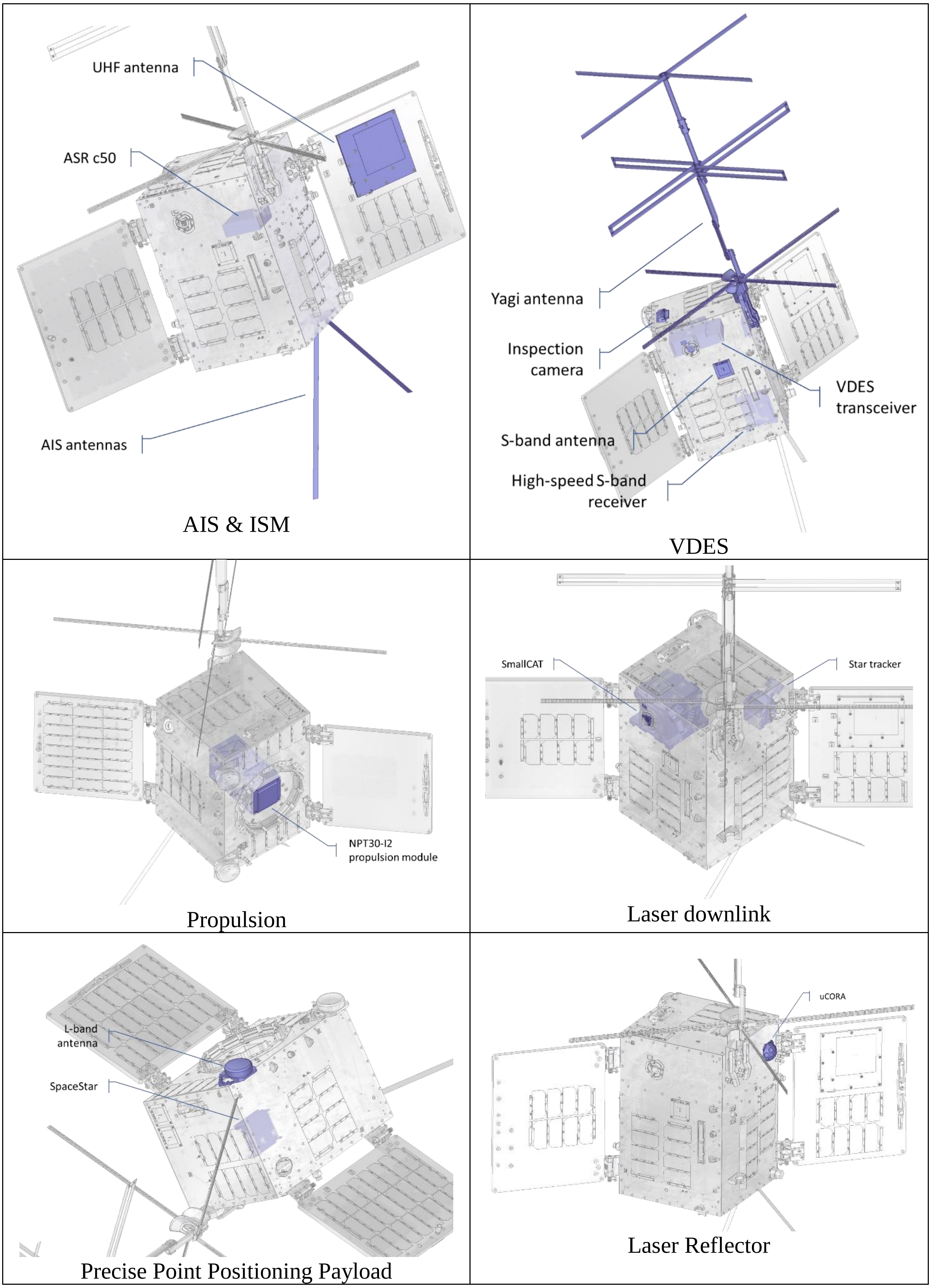

Figure 2: Payload layout

5.1 AIS and ISM Receiver

The AIS and ISM receiver is comprised of the ASR c50 receiver, two orthogonal monopole AIS antennas, and a UHF patch antenna. The receiver module is located in the payload bay of the satellite, as this volume offers the best controlled EMI environment. The two deployable AIS monopole antennas are placed on one of the small satellite faces, and stowed under a solar array. This placement provides good AIS signal reception in most attitudes, as the satellite maneuvers for the secondary payloads. It also provides sufficient separation from the VDES antenna, which deploys in the opposite direction. The UHF patch antenna is placed on the nadir side of a deployable solar array, making efficient use of the available external surface area.

5.2 Space VDES

The VDES payload consists of the VDES transceiver, a deployable Yagi antenna, antenna drive electronics, and filtering. Additionally, a high-speed uplink receiver is added to the satellite to support this payload's operations, and a camera is used to confirm the successful deployment of the Yagi antenna. The transceiver, antenna drive electronics, and filters are located in the payload bay due to the available volume, and the bay's controlled EMI environment. The deployable Yagi antenna, which opens by unfolding, is placed along the long edge of the satellite where it is far from all other appendages which could interfere with deployment. Once deployed, it points in the opposite direction to the AIS antenna. This orientation is optimal for its nominally limb-pointing mode.

The high-speed receiver is located in the radio bay with the bus' telemetry and command radios. The high-speed receiver antenna is placed on one of the nadir-facing sides of the satellite, casting a hemispherical pattern towards the Earth. This configuration allows for the simultaneous contact between a ground station and the high-speed receiver, and between the VDES antenna and maritime traffic.

5.3 Electric Propulsion

The electric propulsion is placed in the interstitial bay, in a volume dedicated to this purpose. The thrust-generating face of the propulsion system exits through the middle of the separation ring, taking advantage of space that is otherwise underutilized. The central location of the propulsion system within the bus places the thrust vector nearly through the center of mass, minimizing disturbance torques.

5.4 Laser Downlink Terminal

The laser downlink terminal and the star tracker are both located in the payload bay. These two units are mounted onto the same primary structure to allow for tight tolerancing of their relative orientation, and for better control of static and dynamic misalignment.

The laser downlink aperture is placed on the nadir face of the satellite, while the star tracker aperture is on the zenith side, such that the star tracker is pointed to deep space when the laser terminal is pointed at an optical ground station. The angle between the laser downlink boresight and star tracker boresight is optimized to keep the Sun out of the star tracker's field of view.

5.5 Precise Positioning Payload

The precise pointing payload consists of a computational unit, and an active L-band antenna. The computational unit is located in the radio bay due to the available space there, and due to its sensitivity to the EMI environment. As the L-band antenna receives signals originating from geostationary satellites, it is placed on the zenith-facing side of the satellite.

5.6 Laser Retroreflector

The laser retroreflector is positioned externally, on a nadir-facing panel, where it can be illuminated by laser ranging ground stations.

6 ELECTROMAGNETIC COMAPTIBILITY

A number of other systems design considerations pertaining to the accommodation of multiple diverse payloads and their interaction went into the design of the NorSat-TD mission. One such notable consideration pertains to the Electro-Magnetic Interference (EMI) and Electro-Magnetic Compatibility (EMC) of the various payloads with one another, and with the bus. This is especially important on NorSat-TD, which contains a number of sensitive Radio Frequency (RF) receivers and powerful transmitters. A combination of sound EMI/EMC design, analysis, and test was used to ascertain that transmitters would not interfere with the operations of, or damage the receivers.

The sensitive systems on the bus are the two S-band command receivers, and the GPS receiver. It was important to ensure that payloads would not generate interference that would inhibit the bus' ability to receive commands from the ground, or to lock onto GPS satellites. From the payload side, the AIS receiver, VDES, and Precise Positioning Payload all contain RF receivers which can be susceptible to EMI.

While the only intentional RF transmitters on the satellite are the S-band telemetry transmitter and VDES transceiver, all payloads have the potential to generate unintentional emissions. When analyzing and testing interference between payloads, we consider interferences which can temporarily affect the operations of a payload, and interference which can cause permanent damage. For the former, only those combinations of payloads which are active in the defined use cases need to be analyzed and tested. For the latter, all possible permutations of transmit and receive payloads are analyzed, even if those combinations are not part of any use case. This is done to ensure that operational mistakes will not result in permanent damage.

In some situations, as with the AIS receiver and the VDES transmitter which operate over the same frequency range, and are part of the same use case, interference is unavoidable. Here an operational workaround is used. When in transmit mode, the VDES transmitter is allowed to transmit in bursts, allowing for sufficient gaps for the AIS receiver to capture transmissions from maritime traffic.

A risk-reduction EMC test was performed to ensure the correct functionality of the system. To facilitate performing this test as early as possible, a partially integrated bus was used together with engineering model payloads. These payloads were representative of the flight models from an EMI sense. Figure 3 shows the satellite in an anechoic chamber undergoing EMC testing.

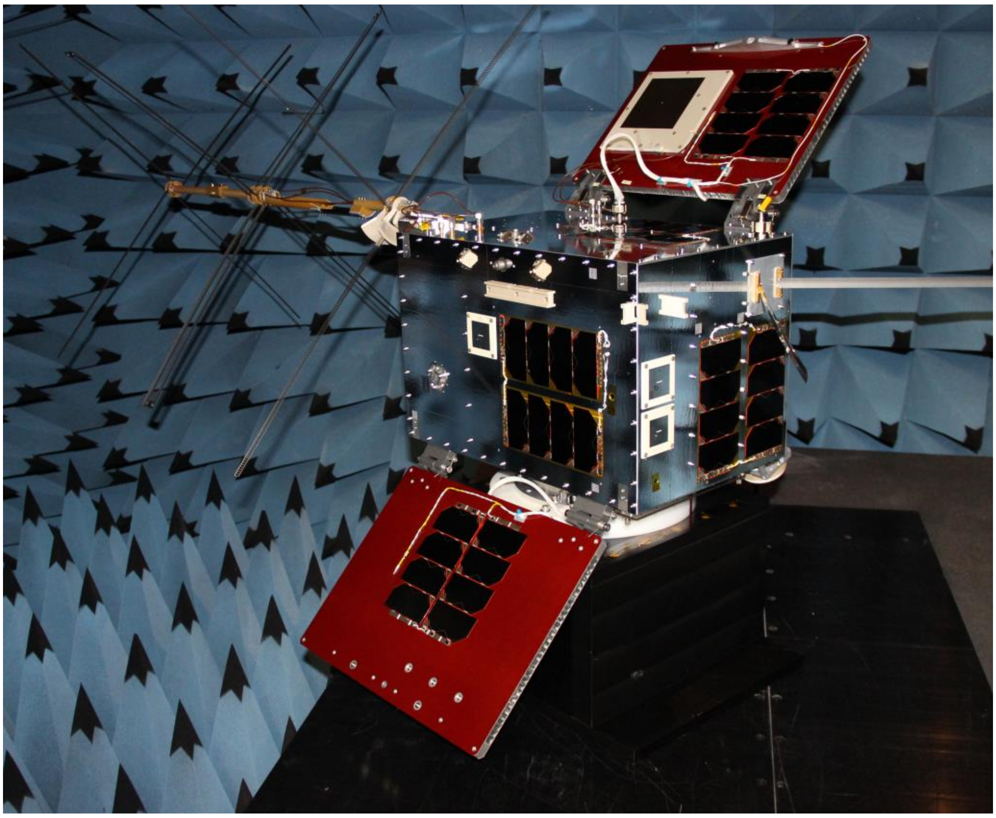

Figure 3: NorSat-TD in risk-reduction EMC testing

7 CONCLUSION

In this paper we described an upcoming mission which incorporates six unique payloads. The satellite will perform its primary mission collecting AIS messages, while simultaneously performing experiments with the in-orbit demonstration payloads. It was shown how SFL's generic DEFIANT platform provides the required flexibility to accommodate these payloads, and to meet their unique and sometimes conflicting requirements. At the time of writing, the NorSat-TD satellite is predominantly integrated, awaiting the readiness of two outstanding payloads. It is expected to launch in the first quarter of 2023.