NANOSATELLITE EAGLET-1 READY FOR LAUNCH

Antonella Simonetti[1] Alberto Franzoso[2] Enrico Saggese[3] Fabio Gerace[4]

(1) OHB-I, Via dei Berio 91 00155, Rome, ASimonetti@cgspace.it
(2) OHB-I, Via Gallarate 150, 20151 Milan, AFranzoso@cgspace.it
(3) On-Air Consulting & Solutions, Via Messina 30 00198 Rome, Enrico.Saggese@onaircs.com
(4) TMC Italia, Via G. Puccini 9 00198 Rome, FGerace@cgspace.it

SUMMARY

The first OHB nanosatellite for Earth Observation has reached its final testing stage and is ready for launch, with Space Flight, from Vandenberg Air Force Base, during August 2018.
Eaglet is a 3U+ satellite with 5m panchromatic resolution capabilities, using a 300-mm focal length telescope with an aperture of 85 mm. The overall mass is less than 5 kg. The satellite has a precise attitude control system based on Earth, Sun, Star Tracker and GPS sensors.
The attitude control system makes use of reaction wheel and utilizes magneto-torquers for their desaturation. In addition to the EO mission, Eaglet shall embark an AIS payload.
The Eaglet QM has undergone thermal vacuum tests at the end of 2017 and vibration test in early 2018, showing full compliance with the specification.

1 THE EAGLET-1 SATELLITE

The first OHB-I nanosatellite for Earth Observation has reached its final testing stage and is ready for launch, with SpaceFlight, from Vandenberg Air Force Base, scheduled at the beginning of August 2018. The satellite will be delivered at 575± 10 km altitude and 97.2° inclination, for an almost sun-synchronous orbit. The nano-satellite is a CubeSat 3U+ (10cm x 10cm x 34cm), for Earth Observation and for AIS (Automatic Identification System) data relaying. The 3D model is given in Figure **1**.

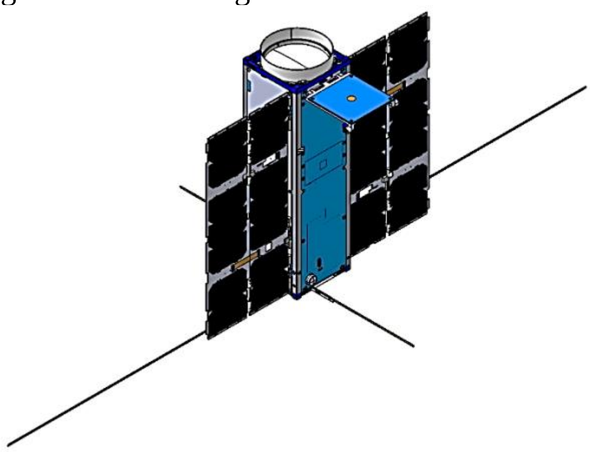


Figure 1 EAGLET 1 CAD model

The EO payload allows a GRD of 5m for a 12 Mpixel panchromatic sensor, using a 300-mm focal length telescope with an aperture of 89 mm. The images are downloaded via a X-Band 30 Mbit/s link to a ground station in Rome.
An AIS transponder receives the ship-generated VHF signals retransmitting them at UHF. These data contain position, course, speed and other information generated by ships over 300t.
The TT&C system makes use of VHF/UHF bands, sharing two dipole antennas with AIS.
The TT&C antenna is located in Rome, too.

The telemetry signal will be at 9,6 kbit/s while the commands will be transmitted at 1,2 kbit/s.
The overall satellite mass is less than 5 kg. Two deployable solar panels 30x40 cm^2 total area) and

an on-board battery (30Ah) will ensure the possibility to generate and store the required energy to operate the satellite and to take up to 100 pictures to be loaded in the on-board memory.
The attitude control system uses reaction wheels and magneto-torquers for their desaturation.
The satellite has a precise attitude control system based on Earth, Sun, Star Tracker and GPS sensors, allowing a pointing within 500m from the target at 3 σ.
The RF power at X-band will be 1W while the X-band antenna, deployable, will be a single patch with a gain of 4.5dB.
The payloads have been designed and manufactured by OHB-I while the bus has integrated COTS elements whenever possible. [1]
The mechanical assembly is presented in Figure 2

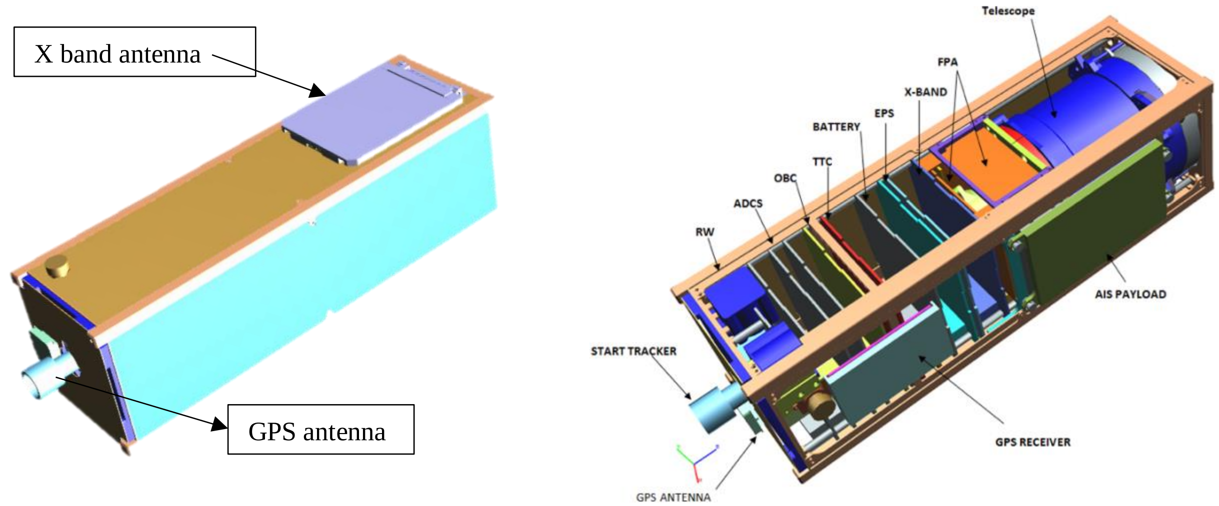


Figure 2 Eaglet-1 Mechanical Assembly

2 MISSION OVERVIEW

The mission concept is to design a low cost nano-satellite aiming at providing optical medium resolution Earth images and relaying ships originated AIS signals to ground, playing the role of technologic demonstrator. The primary Area of Interest is the Mediterranean Area, even though operations are foreseen on a global basis.
The satellite will operate in a quasi sun-synchronous orbit to be set at 575 km of altitude, with an eccentricity in the range 0÷0.0043 and a LTDN at 10:30 a.m. Since the satellite has no propulsion system, the effective orbit will be the one obtained by the launcher and primary satellite needs. [2]
The mission profile is based on the following:

- Sun Pointing attitude as nominal satellite attitude: deployable solar panels are used.
- Nadir Pointing attitude during images acquisition.
- Minimization of manoeuvres number to increase the mission architecture reliability.
- Minimization of tangential and transversal temperature gradient of telescope assembly to optimize optical system MTF

All the listed requirements are fulfilled with the following nominal mission profile:

- Initial orbits: the attitude is sun pointing both during lightened and shadow orbit segments.
- Acquisition Orbits: nadir pointing attitude only on the area of interest. Sun Pointing attitude is maintained during the remaining orbit segment.

The mission architecture is optimal in term of power budget and number of maneuvers per orbit. Telescope temperature gradients could also be controlled through an active control law if required by the actual sun illumination values.
These considerations were the basis for the thermal control and analyses to be verified during the TV test.

3 THERMAL ASPECTS

The EQM of the satellite has undergone thermal vacuum tests for a complete assessment of the thermal model. In the following the thermal design constraints are defined together with the temperature limits and the satellite expected performance are given. The TV tests are then explained, and the final results are shown.

3.1 Thermal design constraints

The satellite power dissipation budget is given in Table 1 while the Design temperatures are given in Table 2, for some of the temperature control points.

Table 1 Power Dissipation Budget

	Power Dissipation				
Op Modes	**SP P/L Off**	**SP AIS On**	**NP Acq, Tx On**	**NP P/L On**	**NP Acq. On**
OBC	0.39	0.39	0.39	0.39	0.39
EPS	0.58	0.87	3.26	3.52	3.07
Battery	0.10	0.10	0.10	0.10	0.10
ACS	1.30	1.30	1.30	1.30	1.30
GPS	0.00	0.00	1.20	1.20	0.00
TTC	0.37	1.67	1.67	1.67	1.67
VHF Antenna	0.02	0.02	0.02	0.02	0.02
AIS Tx	0.25	0.25	0.25	0.25	0.25
AIS RX	0.00	4.50	0.00	4.50	0.00
FPA	0.00	0.00	5.28	5.28	5.28
XBand TX	0.00	0.00	6.00	6.00	0.00
TOTAL:	3.01	9.10	19.47	24.23	12.08

SP=Sun Pointing, NP=Nadir Pointing, Acq.=Optical acquisition, Tx On= X Band transmitter switched on, AIS On = AIS payload switched On.

Table 2 Units Design Temperatures

Element	DESIGN TEMPERATURES			
	Min Non Op	Min Op	Max Op	Max Non Op
+Y Panel	-20	-15	40	60
Battery	-20	-10	50	60
EPS	-50	-40	85	100
X-band TX	-50	-40	50	60
Focal Plane Assy	-40	-30	50	60
AIS 1	-40	-30	50	60

The quality of the images (MTF, i.e. Modulation Transfer Function) is dependent on the telescope temperature gradients due to the different expansion coefficients of glass and telescope structure, so control points and heaters are positioned in some parts of the telescope where extreme temperature are possible: the target gradients are 7°C longitudinal and 2°C transvers maximum peak to peak.
The heater brings also the possibility, in cold cases, to put the telescope mean temperature within the athermalization range: -20/+60° C. It has also to be considered, in the attitude choice of the satellite, that Nadir pointing greatly reduces the temperature extremes in the telescope front lens: pointing deep space produces a surface temperature down to -40°C.

3.2 Thermal Model

A Thermal Mathematical Model (TMM) and a Geometrical Mathematical Model (GMM) have been built, to simulate the behaviour of the satellite during flight. Systema/Thermica 4.7.1 software has been used to calculate the environmental thermal fluxes (Solar, Albedo and Earth IR), and the radiative couplings among the satellite components and space. ThermiSol was used to solve the thermal network and to compute the temperature maps of the satellite according to the different mission scenarios, combining the power dissipation profiles and the attitude constraints.

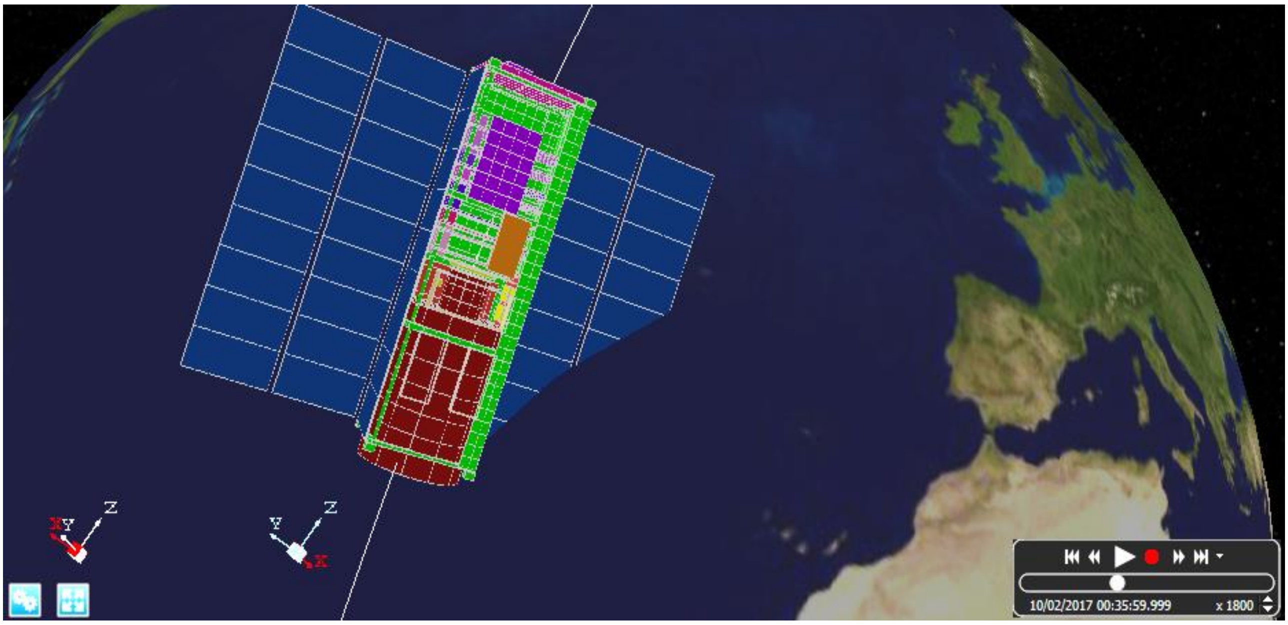


Figure 3 Eaglet-1 Geometrical Model

The thermal model contains about 5000 thermal nodes, in order to have an extremely detailed temperature mapping. Very fine meshes have been adopted, to increase the detail level and the accuracy of the predictions, in particular for the most sensitive elements, like the telescope.
Several orbital transient simulations have been run, to optimize the thermal design.
Optical coatings have been assigned to the satellite surfaces, in order to control the temperatures against the harsh and variable environmental conditions. Internal copper links have been introduced, coupled to the boards with soft thermal fillers or flexible braids, in order to transfer the heat in the most efficient way from the hot heat sources to the cold heat sinks. The extremely different power dissipation scenarios (+600% peak power with respect to the nominal dissipation) represented a challenge in this perspective, since the thermal control system has to keep the temperatures within the operational range, against very different internal and external conditions.
Active control through heaters was needed to maintain minimum temperatures during mission cold phases.
Heaters have been included also for the telescope temperature gradients suppression, a necessary feature to improve the images quality.
Specific conductive tape was wrapped around the telescope, to enhance its in-plane thermal conductivity.
A robust and effective thermal design was finally achieved and validated through thermal analysis in the dimensioning cases. Both worst hot and worst cold thermal analyses gave positive margins against the temperature requirements, as reported in the following plot.

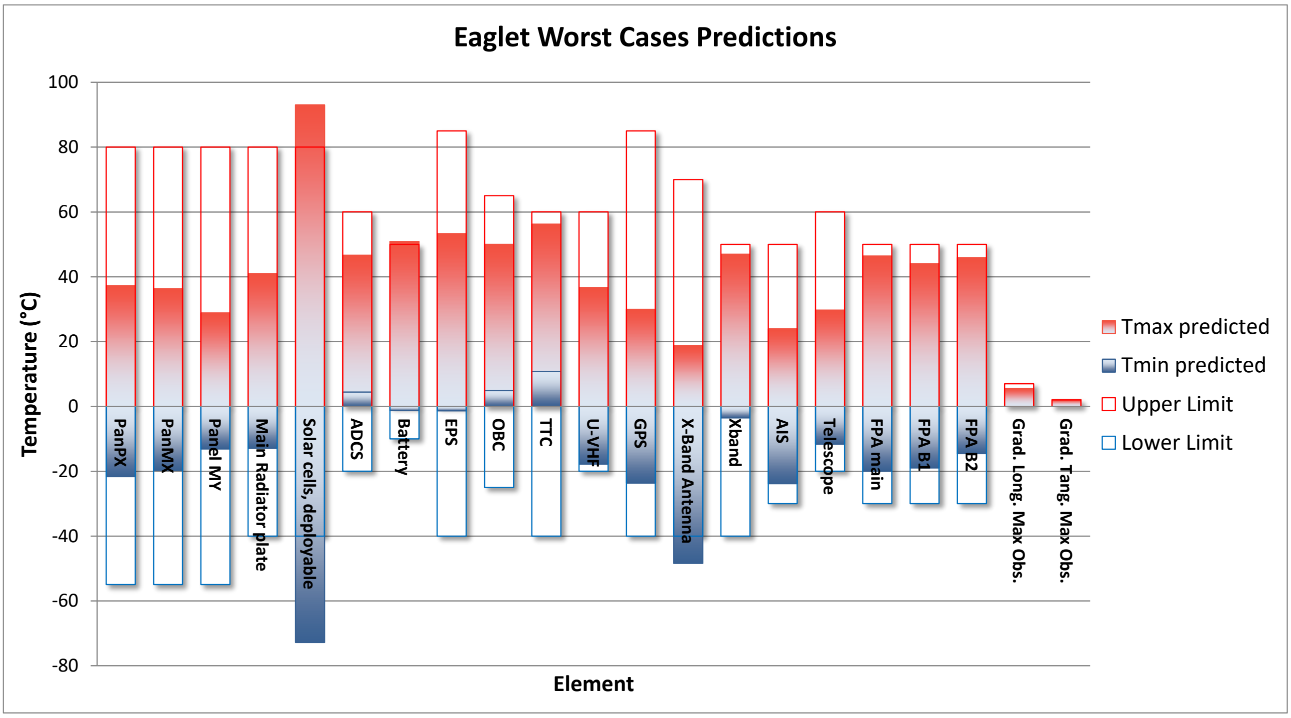


Figure 4 Eaglet-1 thermal analysis temperature predictions

All elements stay within their temperature limits, with the exception of the Solar Arrays, which exceed the nominal operational range at both hot and cold ends and need further delta-qualification in the frame of the Eaglet project.

3.3 Thermal Vacuum Tests

The test set up is given in Figure 5 where it is shown that the device under test is switched on and both electrical and optical parameters are measured by Ground Support Equipment.

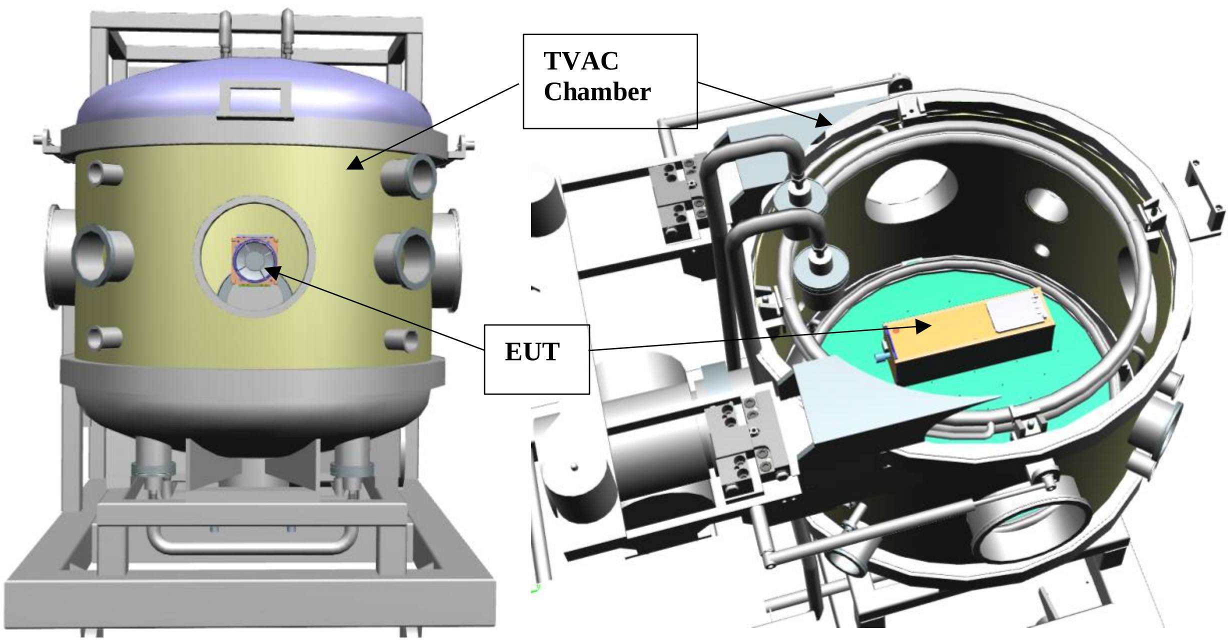
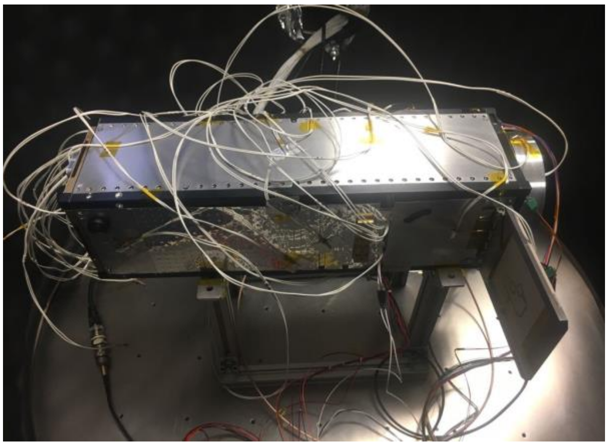


Figure 5 Eaglet-1 TV tests set-up

The EM model of Eaglet-1 undergoing TV tests is represented in Figure 6



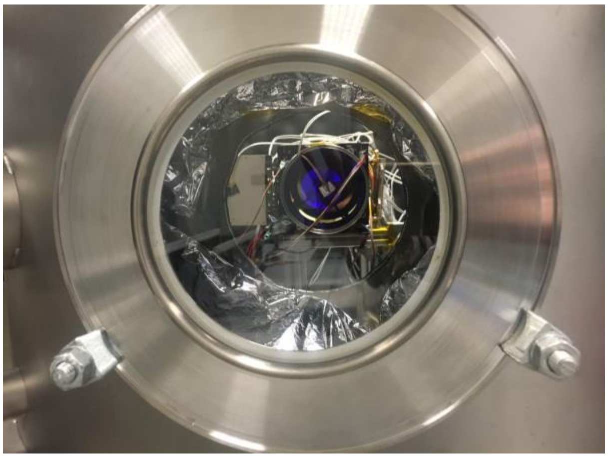


Figure 6 Eaglet-1 preparation for TV tests and in the Thermal Vacuum chamber

In the electronic boards, 20 sensors were acquiring temperature data as well as 6 ones connected directly to the OBC; 30 additional sensors were testing points inside the TV chamber.
The 8 cycles test profile is given in Figure 7. The profiles were at constant dissipation with the exception of hot balance and during tests with units switched on.
Temperature limits were inserted according to the test predictions and using the various board mean temperature.
Minimum and maximum dissipations were considered in hot and cold cases (see Table 3).
Alarm were inserted if temperatures were out-passing by more than 5° the predicted values. The expected limiting factor for the temperature cycling was the battery temperature.
During functional tests, i.e. with the board switched on, a change up to 5-10° C in the shrouds temperature was considered, as suggested in order to avoid excess temperatures inside the boards.
The constant monitoring on X-Band transmitter had the scope to limit the switch-on time if acceptance temperature was overcome in less than 5 minutes. Similarly, the AIS and battery acceptance temperatures was not expected to be overcome in less than 10' and 15' for the Focal Plane Assembly.
Critical aspects were expected also on the power absorption at extreme temperature limits.
Logistics was also an issue and work-shifts were organised in order to have always trained people looking at the on-going tests.

Table 3 Units Limit Temperatures during Tests

Case	Predicted Shroud temp.	Remarks
Max NON OP	+60°C	Value common to several units
Min NON OP	-20°C	Driven by battery
Max OP, Cycling	+15°C	Mode: SA P/L Off, with EPS additional power; if not present, temperature may be increased by up to ~20°C
Max OP, prior to func.tests	<+15°C	Either switch off EPS additional power, or lower shroud temperatures by 5-10°C to carry the operational tests in a safe temperature range.
Min OP, Cycling	-60°C	Mode: SA P/L Off, with battery panel heater and NO EPS power; EPS power would switch off heaters.
Hot Balance	-30°C	Mode: NP Acq. with EPS additional power ON
Cold Balance	-10°C	Mode: SA P/L Off, with NO EPS additional power.

The nominal test profile in terms of temperature and pressure is given in Figure **7**

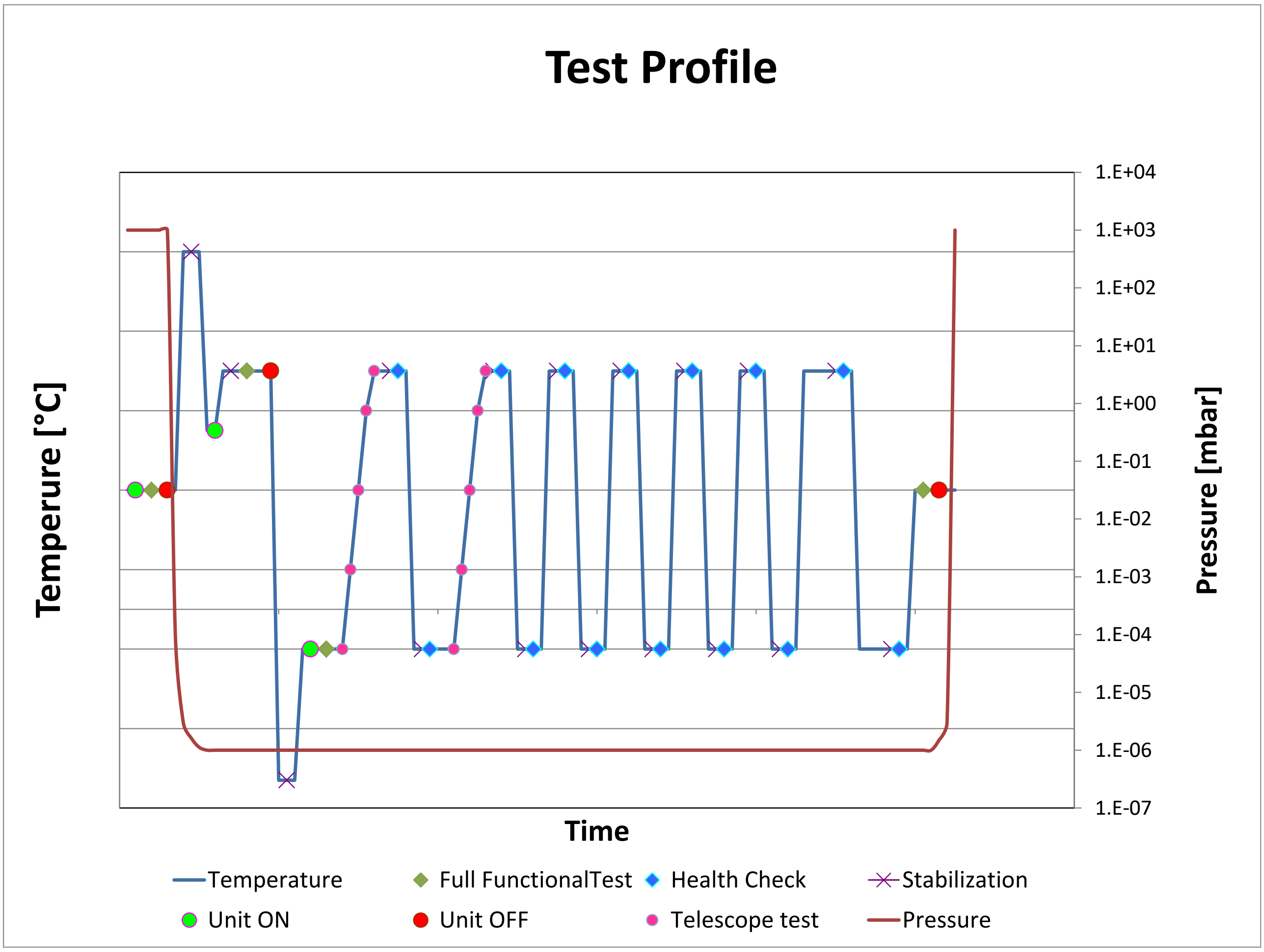


Figure 7 Eaglet-1 TV cycling

3.4 Thermal Vacuum Tests Results

The thermal and vacuum cycling actually obtained is given in Figure 8. The thermal test with an indication of the operational and non-operational periods is given in Figure 9. In the thermal Balance test phase, the test objective is the verification of the mathematical model of thermal characteristics of the subsystem by comparing test results with test predictions.
The test was performed with a stable power dissipation profile (Hot profile and Cold profile).
No functional check was foreseen during this phase, characterized by a stable and constant power dissipation. No heater was active.
In the thermal Cycling test phase, qualification was obtained to provide evidence that the space segment element performs in accordance with its specifications in the intended environment with the specified qualification margins. During the thermal cycling a precise power dissipation power was identified for the hot and cold levels. Functional checks were performed taking particular precaution on the power dissipation to avoid unintended temperature peaks.

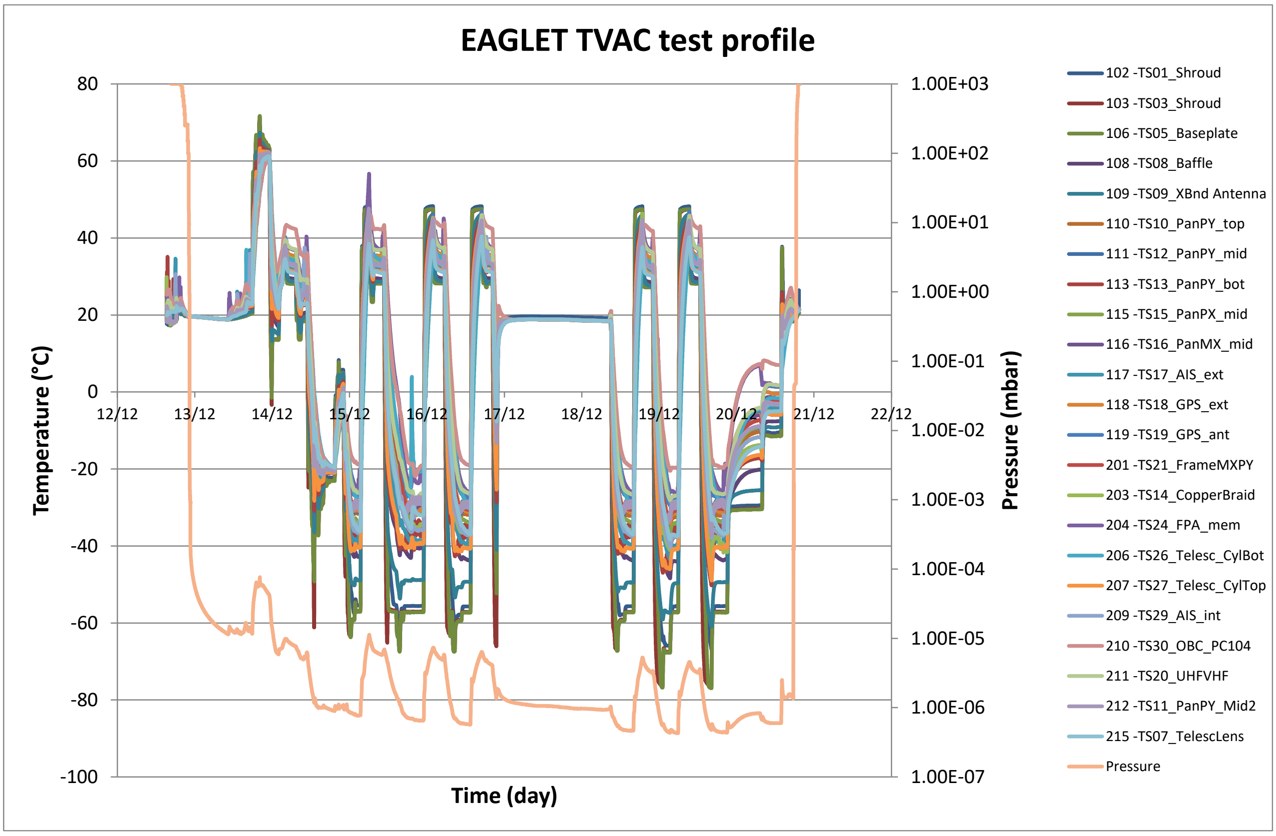


Figure 8 TVAC test profile

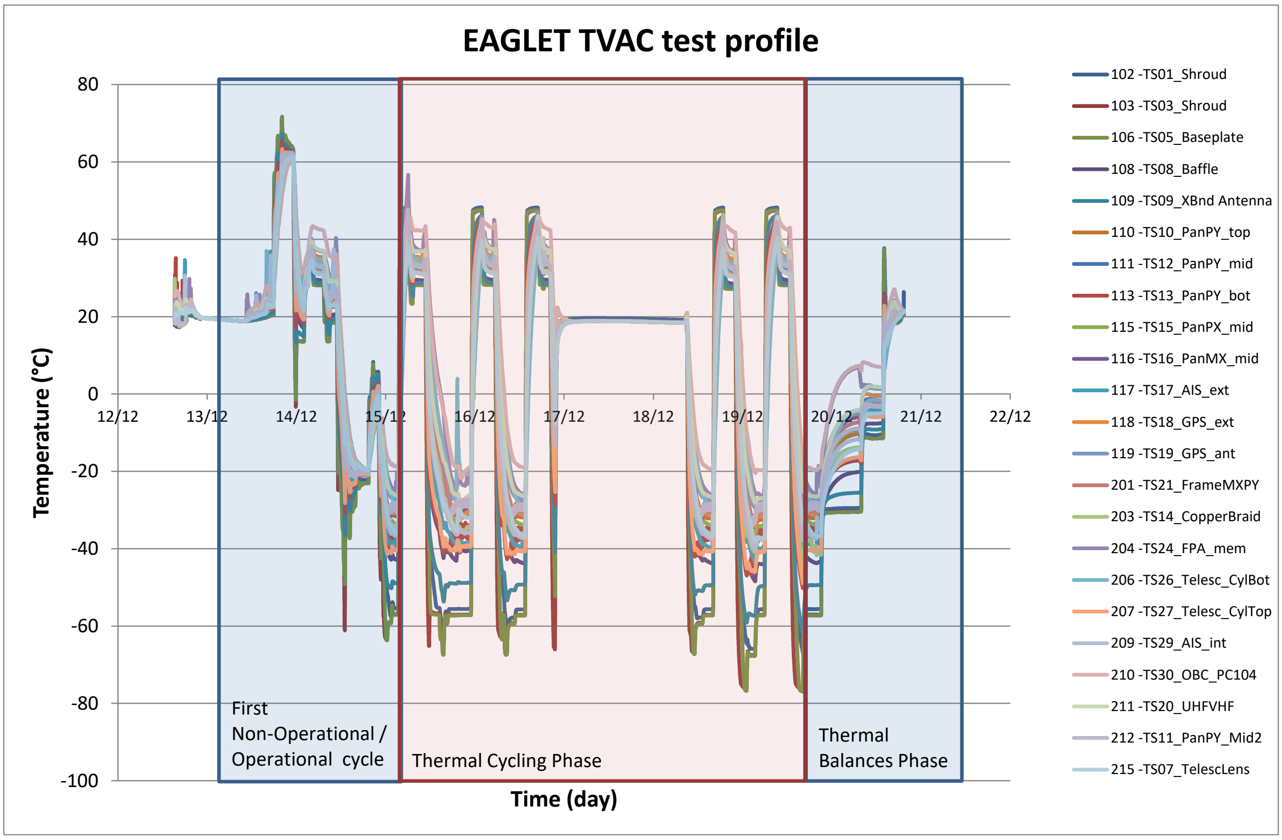


Figure 9 Thermal test profile with phases

The optical measurements were done with respect to an "optical ramp" to judge on the MTF values (see Figure 10).

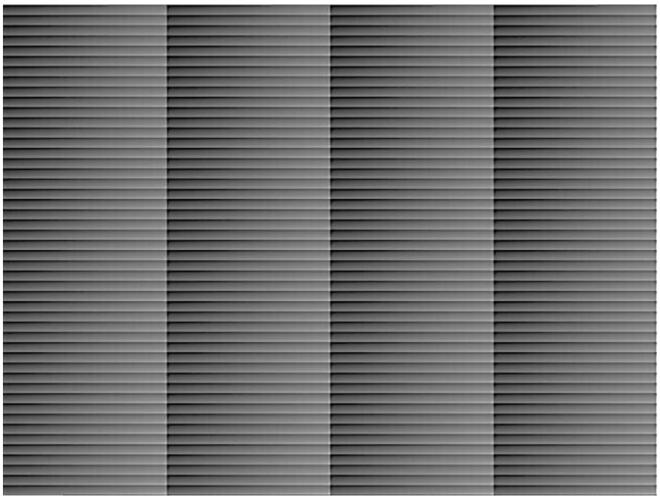


Figure 10 Optical Test Pattern

The thermal vacuum cycling session allowed to validate the thermal design of the satellite, and to qualify it over a wide environmental temperature range, representative of the flight conditions. The main heat paths, which have been designed in order to couple the dissipating internal PCB with the external radiator panels, have shown their effectiveness: the heat generated in the EPS board, and above all in the FPA, was properly transferred to the cold sinks. This kept each part within its operational temperature range and avoided to exceed the tight temperature limits of the battery.

Active control heaters actuation was also verified, showing the robustness of the thermal control system. The effect of the telescope heaters, designed to minimize the temperature gradients along its structure, was also characterized. This allows an accurate heater actuation design, which shall improve the quality of the images acquired by the telescope.

Additionally, significant data was collected during the thermal balance phases. The presence of several sensors installed into the satellite gave precious information about the internal temperature distribution. These data, after comparison with the test predictions, allowed to start the thermal model correlation activities (see Figure 11). This correlation effort shall be complemented and finalized with the results coming from the Flight Unit test; a fully correlated thermal model shall be built to allow the flight operations optimization, in particular aiming at the reduction of the telescope gradients, while limiting the AOCS operations and keeping the power budget under control, thus extending the satellite life and improving the optical performance.

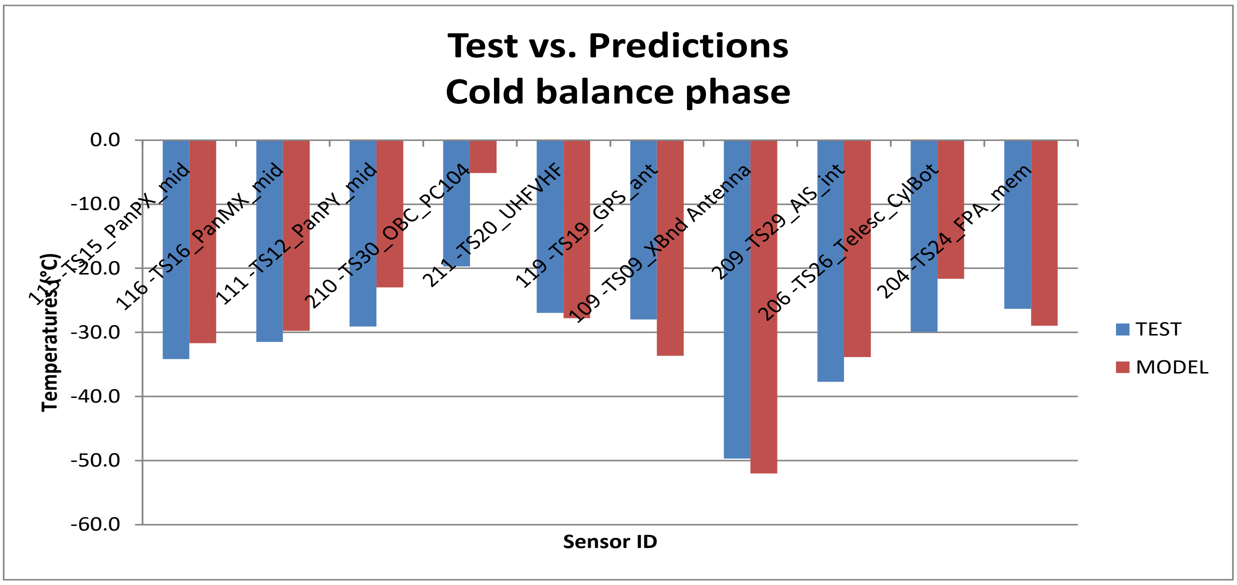


Figure 11 Predicted vs measured temperatures

4 Vibration Tests

According to Spaceflight requirements, the mission environments include:

- Quasi static loads: 15 g applied non-simultaneously to the three orthogonal axes according with GSFC-STD-7000A
- Acoustics: no environment is levied
- Shock: no environment is levied
- Random vibrations: levels according to Figure 12

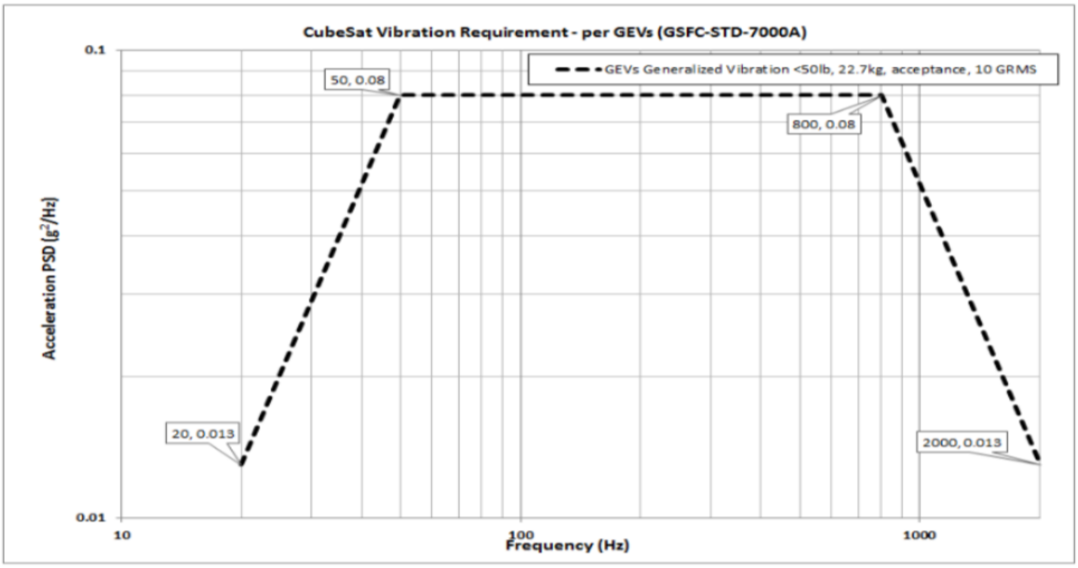


Figure 12 Random vibration levels

- The fundamental frequency of the Spacecraft shall be greater than 150 Hz (All axes).
- Sinusoidal Vibration: for Spacecraft that cannot meet the minimum fundamental frequency requirement, the Spacecraft shall be qualified to the maximum predicted sinusoidal vibration environment shown in the figure below:

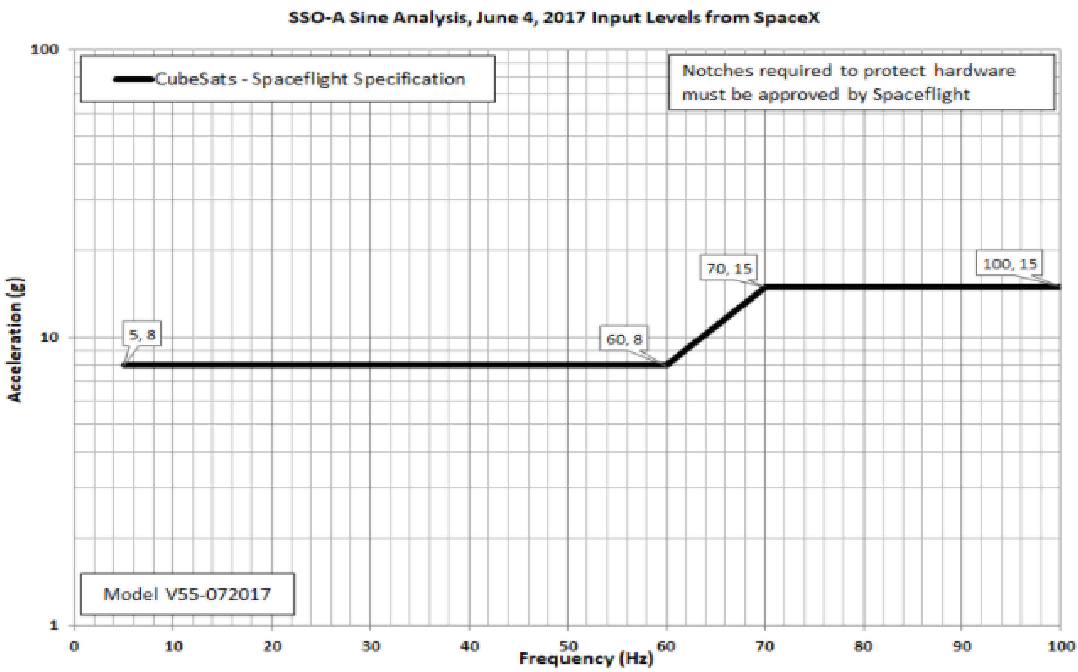


Figure 13 Sinusoidal vibration levels

A triaxial accelerometer was glued by adhesive on the central part of the curved part of the telescope, on the AIS board and on the panels; then the satellite was inserted in the TestPod as per Figure 14.

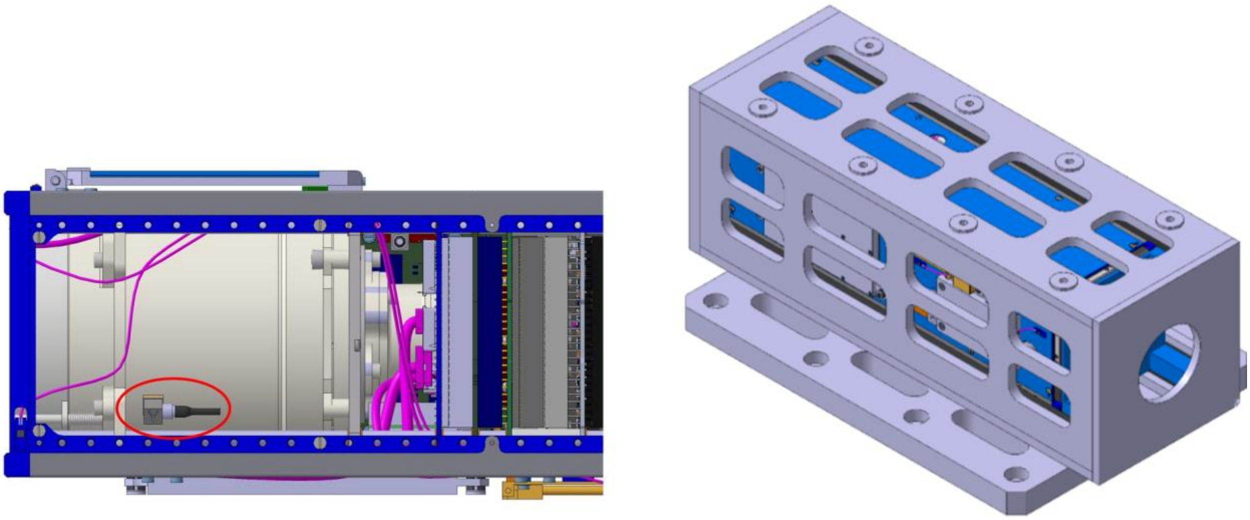


Figure 14 Positioning of the accelerometer and satellite within TestPod

The EQM Model of Eaglet-1 satellite was designed, analyzed and tested to the maximum predicted random and sinusoidal vibration applied non-simultaneously and the test factors and durations provided in Table 4 in three orthogonal axes. The chosen approach for the vibration test campaign was to carry out the test at the acceptance levels first and subsequently at the qualification levels.

Table 4 Vibration Limit Levels during Tests

Test	**Acceptance**	**Protoflight Qualification**
Random Vibration level Duration	Limit level 1 minute/axis	Limit level +3dB 1 minute/axis
Sine Vibration Level Sweep Rate	Limit level 4 oct/min	1.25xLimit level 4 oct/min

The results obtained during the test campaign show a positive system response to the imposed mechanical stresses; the fundamental frequency of the satellite was found to be well above 150 Hz.
As an example of the tests results, the random vibrations imposed along the X-axis did produce accelerations along the three axes and Figure 13 gives the behaviour measured an accelerometer positioned on the telescope.

The vibrations gave positive results, the only non-conformities having been the disconnection of the thermal release on one item and the loosening on a ring which will be better tightened.
No malfunction was recorded on the electrical behaviour and performance of the satellite boards.

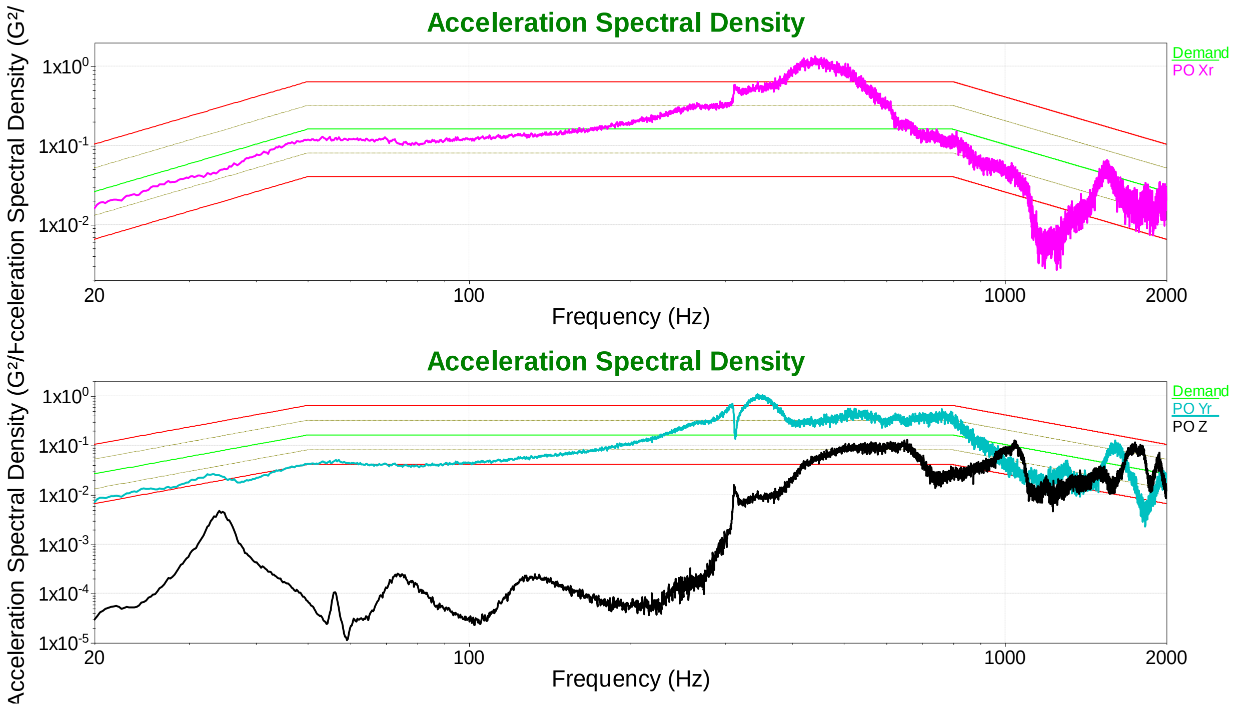


Figure 15 Random vibration test results for Optical payload in X direction.

5 CONCLUSIONS

Eaglet-1 EQM has undergone environmental test campaigns for thermal vacuum and vibration tests. Both of them have given positive results, so the model is definitely qualified for space environment. The results of the campaign have been presented in the paper.
The integration of the flight model has started and the subsequent flight acceptance test campaigns will be shortly conducted.

6 AKNOWLEDGEMENTS

The work performed on Eaglet 1 has seen the cooperation of many professionals in OHB-I and in other companies; the authors would like to thank all of them and in particular M. Severi, R. D'imporzano, I. Corradino, M. Messeri, V. Lamarca, M. Gaeta, L. Maioli and V. Speziale.

7 REFERENCES

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[2] A. Simonetti, M. Gaeta, V. Lamarca, L. Maioli, F. Piergentili, F. Santoni, E. Saggese, *A CubeSat Constellation for Maritime Surveillance*, 68th International Astronautical Congress (IAC), Adelaide, Australia, 25-29 September 2017.