

Environmental Test Campaigns of the Focal Plane Assembly for PLATO Mission at INTA

A. Manjón^{*a}, M. Pajas^a, P. Gallego^a, I. Catalán^a, A. Rodríguez^a, A. de Pedraza^a, M. A. Alcacera^a,
F. J. Donaire^a, C. Fernández-Muñoz^a, A. Carretero^a, A. Balado^a, J. M. Mas-Hesse^b

^aINTA, Instituto Nacional Técnica Aeroespacial, ^bCentro de Astrobiología, INTA-CSIC
Ctra. Ajalvir, Km. 4 28850, Torrejón de Ardoz, Madrid, Spain.

ABSTRACT

PLATO (PLANetary Transits and Oscillations of stars) is a mission of the European Space Agency (ESA) aimed at the detection and characterization of extrasolar planetary systems, with particular emphasis on Earth-like rocky planets orbiting Sun-like stars within their habitable zones.

The PLATO payload consists of an array of 26 cameras mounted on a common optical bench, providing a very large field of view to achieve its scientific objectives, together with the associated Data Processing System (DPS) and the Instrument Control Unit (ICU). Each camera is a complex instrument comprising a Telescope Optical Unit (TOU), a Focal Plane Assembly (FPA), and a Front-End Electronics unit (FEE).

Given the requirements of the mission for a high-rate flight hardware production, a dedicated verification strategy was required from the early stages of the project. This strategy incorporated early and redundant qualification phases, to lighten the final flight model acceptance stage, with a total of 26 flight FPAs (plus 3 spares) delivered.

This paper describes the tests performed during the different environmental test campaigns of the PLATO mission's Focal Plane Assembly starting with a high-maturity prototype, through the structural and thermal model and qualification model phases, and concluding with the delivery of the final flight models. It also summarizes the main decisions, risks and considerations associated with these aspects throughout the project, together with the rationale behind them.

In total, 18 FPAs (comprising 72 CCDs) have been tested at INTA facilities, with 15 acceptance tests campaigns performed on the flight models over a period of approximately two years, under strict contamination control protocols.

Keywords: Exoplanets, PLATO, validation, testing, AIVT, FPA, CCD.

1. INTRODUCTION

PLATO (PLANetary Transits and Oscillations of stars) is the ESA's Cosmic Vision Programme M3 mission selected by the Science Programme Committee for launch in 2027. This mission will detect terrestrial exoplanets in the habitable zone of solar-type stars and characterize their bulk properties. PLATO will provide the key information (planet radii, mean densities, stellar irradiation and architecture of planetary systems) needed to determine the habitability of these unexpectedly diverse new worlds [1][2].

PLATO is composed by a total of 26 cameras in the payload, 24 normal cameras (N-CAM) and 2 fast cameras (F-CAM). Each camera includes:

- Telescope Optical Unit (TOU)
- Focal Plane Assembly (FPA), holding 4 Charge-Coupled Device sensors (CCDs)
- Front End Electronics (FEE)
- Thermal Control System (TCS)
- Multi-Layer Insulator (MLI)

INTA is responsible of the design development (design performed the company LIDAX), assembly, integration, alignment, verification and testing of the FPAs [3].

*amangal@inta.es; phone +34 915202137; www.inta.es

The FPA is composed of a support structure with four large CCD sensors and flexi cables, a mask to protect them from radiation and straylight, and to provide stiffness to the plate, the hardware providing the structural interface to the TOU (bipods, fasteners and shims) and the thermal hardware needed to dissipate the CCDs heat.

The main functions of the FPAs are:

- To provide mechanical support to four detectors
- To provide straylight and radiation protection to detectors
- To provide mechanical interface with TOU being compliant with high mechanical solicitation, alignment and stability requirements
- To provide an electrical interface to FEE box
- To provide thermal coupling of CCDs to TOU to ensure temperature dissipation.

In the final design, the FPA main components are as follows:

- CCD Support Structure (x1): a titanium plate which provides support to CCDs, as well as protection against straylight and radiation.
- CCD (x4): optical detectors manufactured and delivered by Te2v, with the sensitive area bonded to SiC package and the corresponding flexi cables included.
- Bipods (x3): titanium made and black coated, to provide the required isostatic interface to TOU.
- Straylight Mask (x1): titanium made and black coated, it provides straylight and radiation protection to CCDs.
- Thermal Straps (x4): copper made, which provide the required thermal link between CCDs and TOU.
- Flexi Feedthroughs (x8): titanium made with a silicon pad, they provide mechanical support to protect the CCD flexi cables.
- Thermal Strap Supports (x8): titanium and vespel made, to provide mechanical support to thermal straps.
- TOU interface items: for alignment and holding functions.

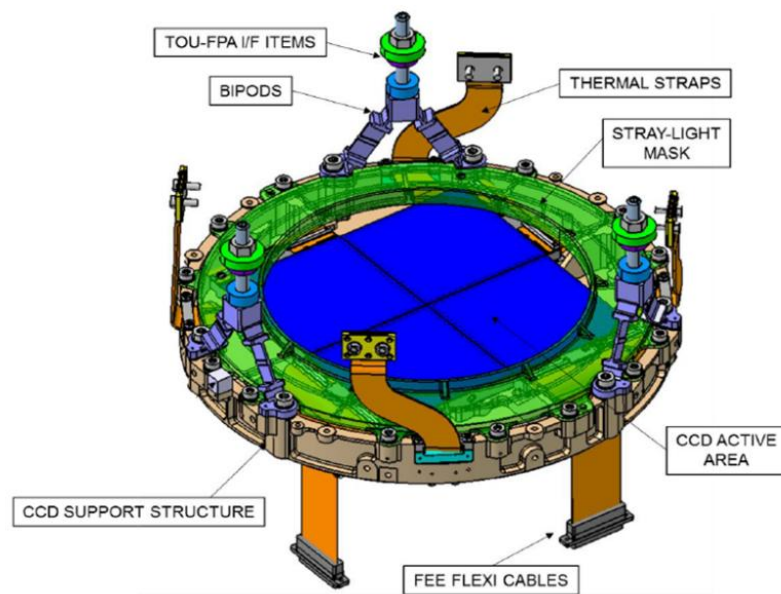


Figure 1. FPA final design main components.

2. PLATO FPA ENVIRONMENTAL TEST CAMPAIGNS AT INTA

The goal of an environmental test campaign is to guarantee that the unit is able to withstand all the mechanical loads produced during the launch and separation stages of the flight, and also to survive and correctly perform its science in the severe thermal and vacuum conditions of the space environment.

To achieve this, different kind of mechanical and thermal tests are performed through the different models, and the next list can be taken as typical:

- Mechanical tests
 - Physical properties test
 - Envelope
 - Mass
 - Centre of gravity (CoG)
 - Moment of inertia (MoI)
- Vibration test
 - Sine load
 - Random load
- Shock test
- Thermal tests
 - Thermal vacuum cycling test
 - Thermal balance test

Another main block of a typical environmental test campaign are the electromagnetic compatibility tests, but in the case of PLATO FPA, they were not needed at unit level, so they are out of the scope of this paper.

Usually, a first environmental test campaign is performed on a model that is thermal and structural representative of the preliminary design (STM) and this is also used to correlate the structural and thermal models. Later, after Critical Design Review, a full qualification campaign is performed on the qualification model (QM) and finally an acceptance test campaign is performed on the final flight model (FM), which will fly to space.

In the case of PLATO FPA, with a total of 26 flight models plus 3 flight spares instead of just a single flight model, a different strategy had to be used. Performing a standard acceptance test campaign on each and every FM would have taken a considerable amount of time, which is not compatible with the delivery rate imposed by the schedule, with one unit delivered every 3 months approximately. Therefore, a different approach was used, minimizing the test time consumed for each FM while still collecting enough data to assure that the unit is able to correctly withstand the space environment and discarding any possible workmanship errors, taking also into account that a complete acceptance test campaign would be performed at camera level.

2.1 Prototype Model

Knowing all this from the very beginning, it was decided to perform a first full qualification test campaign in a high-quality prototype of the FPA. This would allow to gather a lot of useful information regarding the structural and thermal behavior of the FPA and the stability of the CCDs in an early stage. This high-standard prototype had an advanced design maturity in all mechanical parts, and it was representative of materials and components, including real, non-functional, CCDs [3][5]. It was submitted to a full qualification campaign, including vibration, shock and thermal tests [6], being this campaign the most demanding in terms of mechanical loads, thermal temperatures and performed tests.

For the physical properties test block, envelope, MoI and mass tests were performed. CoG could not be performed at the time of the test campaign due to an unavailability of the test facility, and the values extracted from the CAD model had to be used instead. This was the only time where the envelope of the unit was measured. With the compliant results of this model, it was accepted to not verify this requirement by test in future models, which would reduce the handling of the unit and exposure of the CCDs. Nevertheless, the dimensions of all the mechanical parts comprising the FPA were tested after manufacturing and accepted by INTA in the corresponding incoming inspection of the hardware.

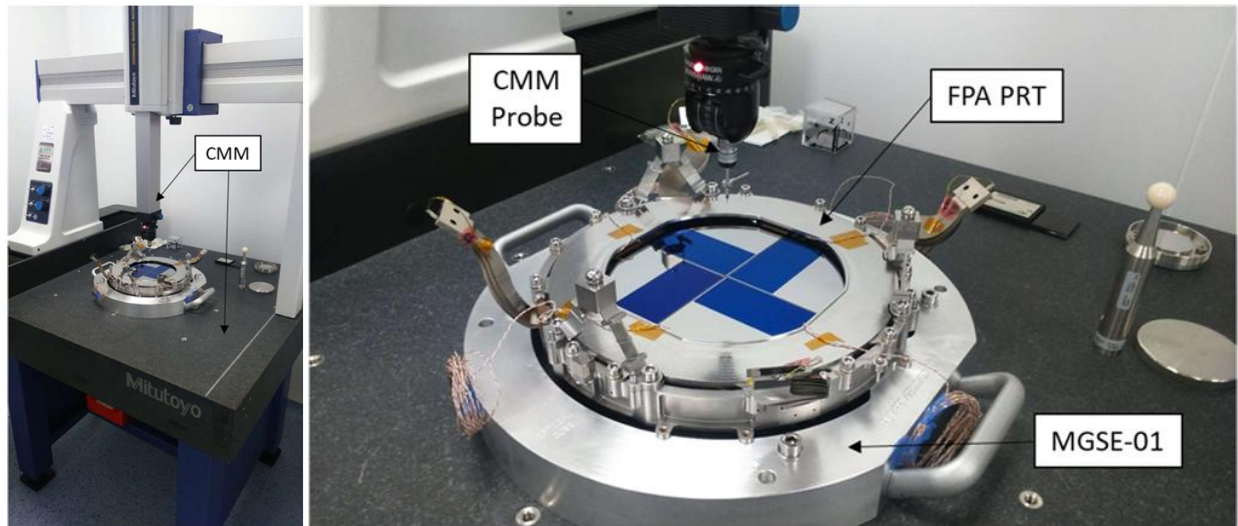


Figure 2. FPA prototype during envelope testing.

In the prototype vibration test, the load levels applied were the highest (50 g in sine load, 16 grms in random), as the load derivation was still in an early stage and wide margins were applied. All three axes were tested, and it was heavily instrumented, with accelerometers located on the CCD surfaces, as they were non-functional. For additional information, a dedicated paper to the different PLATO FPA vibration test campaigns is available [7]. Test results were used for the first correlation of the structural model, performing it in an early stage compared to the standard STM approach.

The prototype shock test was the only shock test performed to PLATO FPA at FPA level. For this test again, heavy margins were applied, and the shock level to be applied was 500 g from 1000 to 10000 Hz. The test was performed in two different configurations (X-Z & Y-Z), with all three axes being tested. Although the test was considered not successful, as the 500 g input loads were not totally reached, it was considered sufficient to demonstrate the survival of the FPA to shock environment, especially the survival of the CCDs when integrated in the FPA, which was one of the drivers of this particular test. In later project stages, the shock loads were relaxed from 500 g to 155 g and it was agreed to perform this test only at camera level.

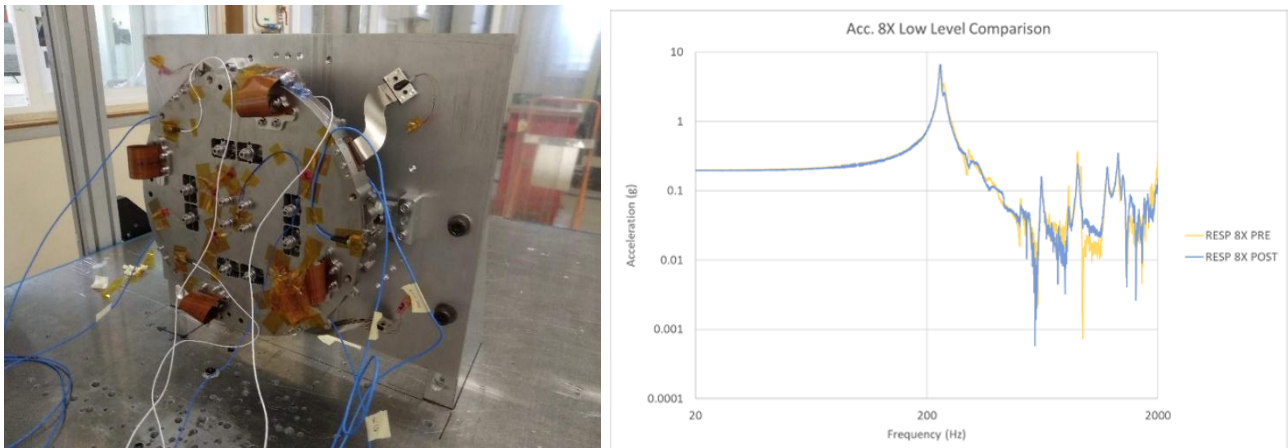


Figure 3. FPA prototype shock test set up and main mode comparisons before and after shock test.

The thermal test of the prototype consisted on a thermal vacuum cycling and a thermal balance test. A total of four cycles were performed, three of them between non-operative temperatures (-115 °C, +45 °C) and one between operative temperatures (-100 °C, -53 °C) at a pressure $\leq 10^{-5}$ hPa. The unit was heavily instrumented, with a total of 29 thermal sensors.

The main objective of this test, apart from the survival of the unit to the operative and non-operative temperatures, was to evaluate the behavior of the thermal hardware of the FPA, the thermal straps that must evacuate the heat coming from the CCDs to the telescope structure. As the CCDs integrated in this model were non-functional, the heat power was simulated with heaters located in the thermal MGSE, as close as possible to the CCD surfaces.

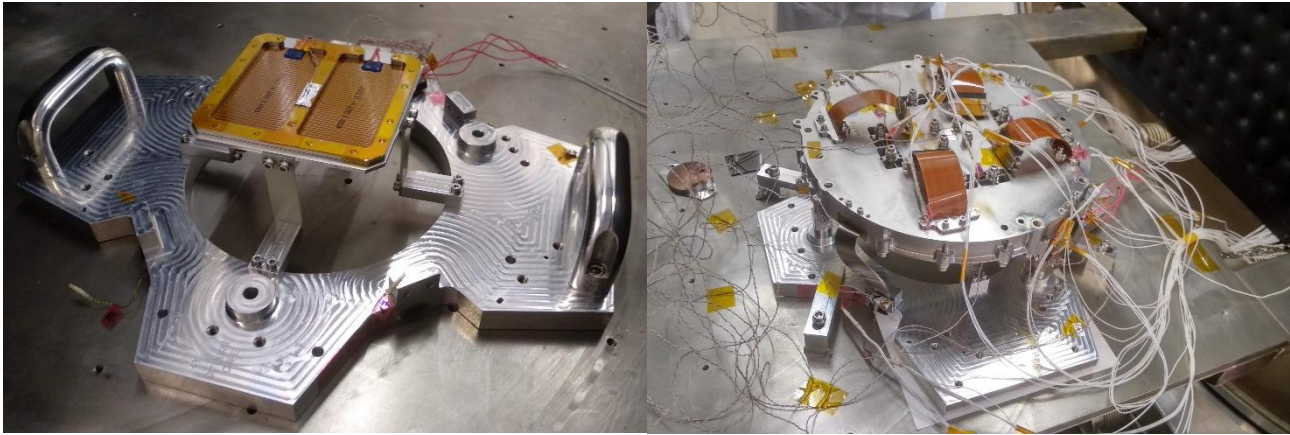


Figure 4. FPA prototype MGSE heaters detail and sensor instrumentation.

The requirement for a good thermal hardware behavior was to have a temperature difference between CCDs (TRP4) and the telescope interface (TRP3) lower than 7 °C, which was successfully achieved, with a maximum difference of 4.1 °C. The operative cycle served also for hot and cold case plateaus for the thermal balance test data obtention and its corresponding thermal model correlation.

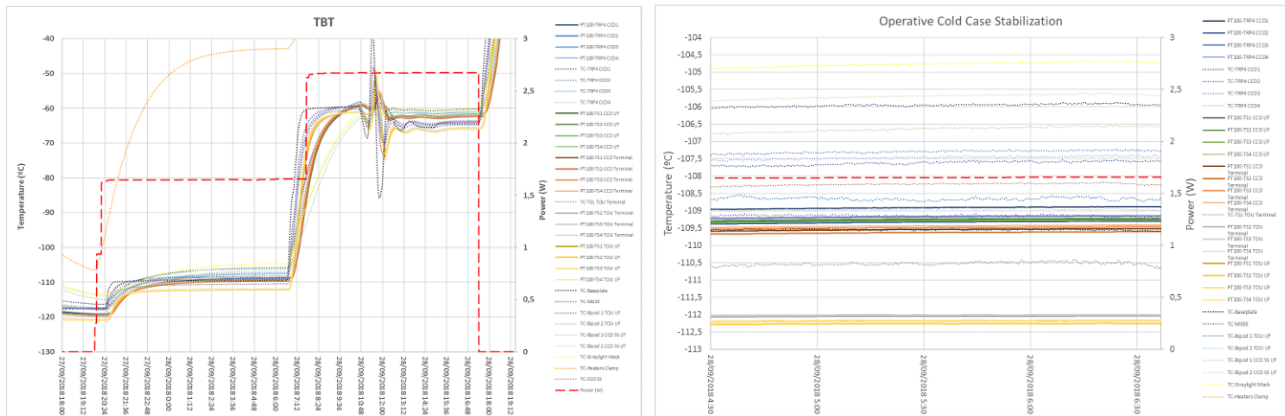


Figure 5. FPA prototype thermal balance test results.

2.2 Structural and Thermal Model (STM)

With all the information gathered from prototype testing, and due to tight schedule, it was decided to perform a reduced environmental test campaign on the STM, consisting in mass, MoI and a reduced vibration test. On the physical properties block, mass and MoI tests were performed, but not CoG, again due to the unavailability of the CoG balance.

For the thermal tests, the decision made was to provide the STM FPA with heaters attached to the non-functional CCDs surface, to simulate the power dissipation for the thermal tests to be performed at camera level.

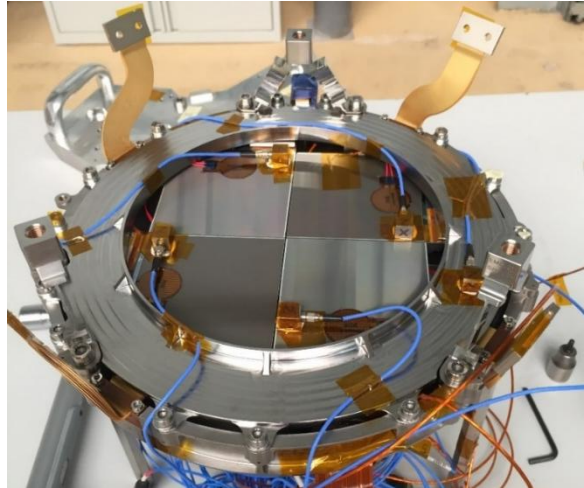


Figure 6. Structural and thermal model as-built unit.

For the vibration test, only Z axis was tested, and a special effort was made to gain knowledge of the real loads seen by the CCDs when assembled in the FPA. The CCDs were thoroughly instrumented for this test, with bonded accelerometers both in the CCD surface and below the ceramic package [7]. This model was delivered to be integrated and fully tested at camera level.

2.3 Qualification Model (QM)

The qualification model included for the first time a new design of the CCD support structure and straylight mask, which were rigidized. This was also the first model to include one completely functional CCD, so functional tests (DC test) were performed on it all throughout the campaign, before and after each handling and testing stage, as a go/no-go check, to demonstrate CCD survival and correct performance.

Regarding the physical properties test block, apart from mass and MoI tests, the CoG test could be performed for the first time since the beginning of the project, with a new CoG balance acquired at INTA.

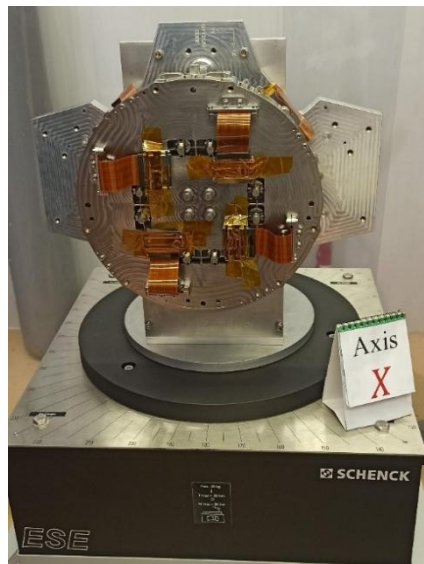


Figure 7. QM model undergoing CoG test.

Both CoG and MoI results were successful (see Table 1) with all values within criteria and obtained with an excellent accuracy. A study was made comparing the MoI results performed between three different models (see Table 2) and also comparing the CoG results with the CAD predicted model with the objective of proposing not to perform these tests again during the FM phase, where a total of 26 models should be tested. Skipping these tests could results in a major schedule saving with also a handling and CCDs exposure to contaminants reduction. At the view of the results, the proposal of not performing CoG and MoI tests during the FM phase was accepted, assuming that the CoG and MoI results were already consistent enough and known with the required accuracy, and that the tests will be also performed at camera level.

Table 1. CoG and MoI test results.

Normal FPA	QM ICD	QM Test Results	QM Test Accuracy	Accuracy Requirement
CoGx	-0.110 mm	-1.65 mm	± 0.01 mm	10 mm
CoGy	-0.484 mm	-0.17 mm	± 0.01 mm	
CoGz	-64.068 mm	-66.50 mm	± 0.01 mm	
MoIx	0.023198 kg·m ²	0.028642 kg·m ²	± 0.003624 kg·m ²	± 0.01 kg·m ²
MoIy	0.023155 kg·m ²	0.028342 kg·m ²	± 0.003366 kg·m ²	
MoIz	0.038927 kg·m ²	0.037297 kg·m ²	± 0.002098 kg·m ²	± 0.004 kg·m ²

Table 2. MoI results comparison between models.

MoI Model Comparison [kg·m ²]					
Axis	Prototype	STM	QM	Max. Variation	Requirement (PLT-FPA-1673)
X	0.021784	0.024177	0.028642	0.006858	All models within ± 0.01 kg·m ²
Y	0.021751	0.023957	0.028342	0.006591	
Z	0.035756	0.032885	0.037297	0.004412	All models within $\pm 10\%$

One of the main objectives of vibration and thermal test was to evaluate that no permanent displacements nor rotations of the CCDs occurred when submitted to the vibration loads and mechanical stresses due to thermal excursion. For this, the position of the CCDs was measured before and after the vibration and thermal tests and compared, with excellent results. The qualification vibration test was performed in all axes with new lower applicable loads (40 g in sine, 12 g_{RMS} in random) and the test results were used for a new correlation of the structural model after the parts modification. [7]

The qualification thermal test consisted on a thermal vacuum cycling. A total of five cycles were performed, four of them between non-operative temperatures (-110 °C, +45 °C) and one between operative temperatures (-100 °C, -53 °C) at a pressure $\leq 10^{-5}$ hPa. The unit was again heavily instrumented, with a total of 26 thermal sensors. As only one of the CCDs was operative, there was no possibility of simulating a representative CCDs power dissipation case, so only functional tests (DC test) were performed on the operative CCD before and after the thermal vacuum cycling to guarantee the survival of the CCD. The full performance tests were carried out at a higher level.

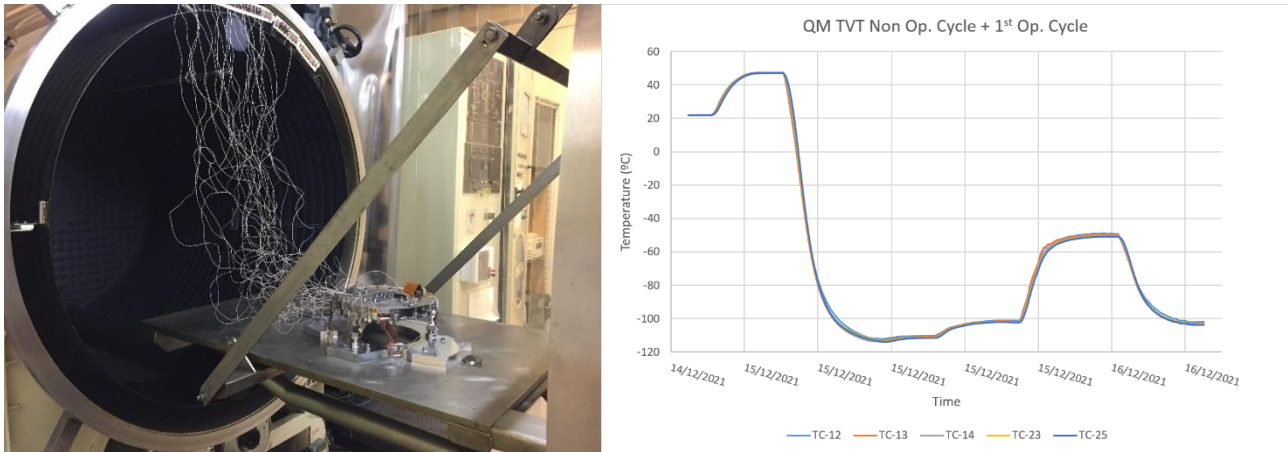


Figure 8. QM model thermal test setup and cycles detail.

2.4 Flight Model (FM)

By the time of proposing the approach for the FM acceptance test campaign, two complete qualification campaigns had already been performed on prototype and qualification models, a lot of information had been gathered from them, and the good behavior of the unit and CCDs was already demonstrated. This allowed to downgrade the FM acceptance test campaign to a reduced vibration workmanship test and a mass test, just to check that the unit is well integrated and results are in line with previous models.

Obviously, the flight models were completely nominal, including real CCDs and the black coating on straylight mask and bipods for the first time. Working with real CCDs implied a severe ESD (electrostatic discharge) control in all related facilities and multiple functional verifications (DC tests) performed throughout the integration, verification and testing phases, to check the integrity and good performance of the CCDs [8].

The cleanliness precautions for these models were totally imperative as, due to FPA design, the CCDs were highly exposed to particulate and molecular contamination. Taking this into consideration, reducing the handling and time exposure on the vibration tests were main goals [9].

This test campaign has been performed on all Normal FPA FMs built at INTA premises, totaling 10 flight models plus 3 flight spares and also on the 2 Fast FPAs built at Te2v but tested at INTA.

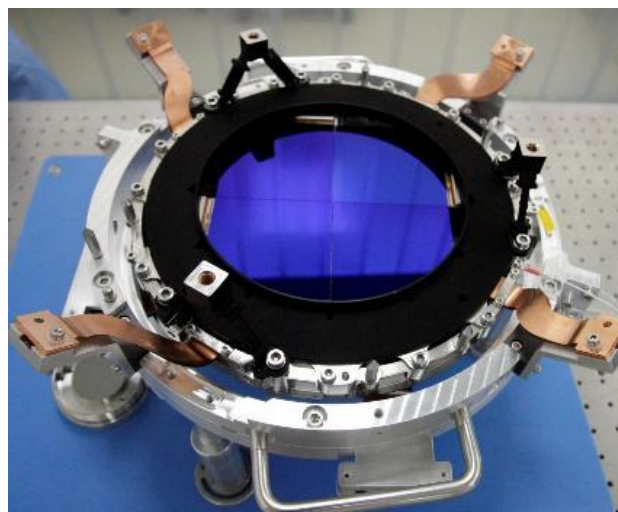


Figure 9. Flight model as-built unit.

The mass test was the only physical properties test performed, after the approval of not performing CoG and MoI due to QM testing justification. The mass was measured on all 15 units tested at INTA and the results of all measured models (at INTA and at Te2v) are shown in figure 10. As can be seen, all the results were compliant and far below the mass requirement, with an average deviation with respect to the nominal mass value lower than 1%.

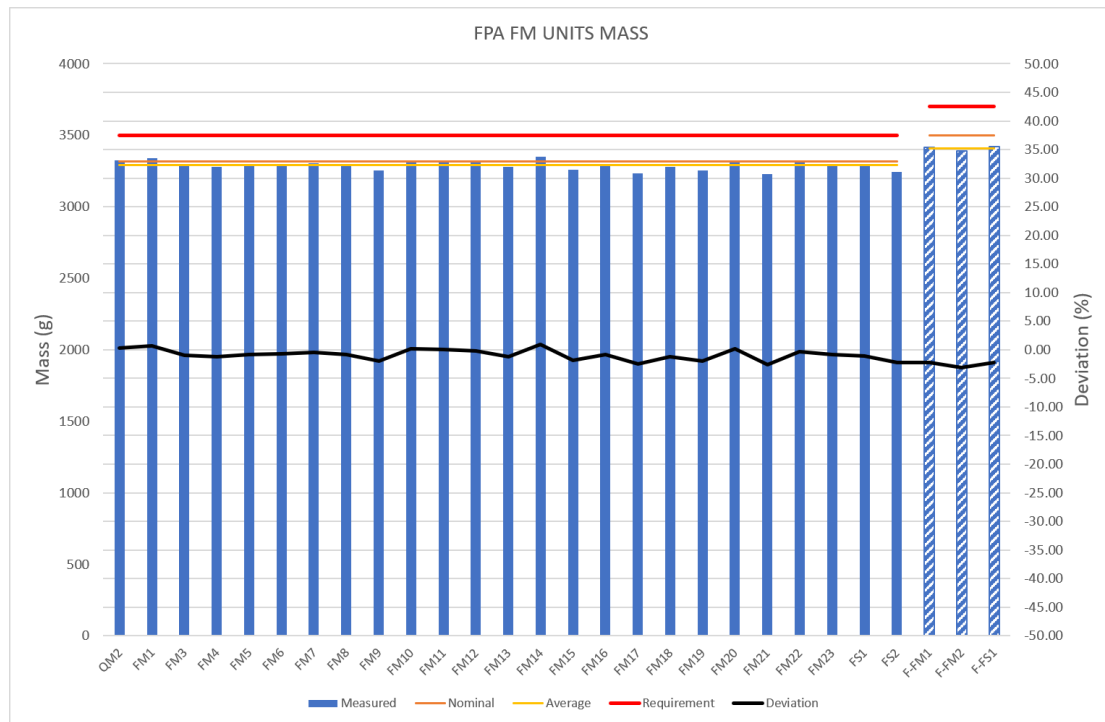


Figure 10. Flight model mass test results

For the FM vibration tests, only Y axis was tested, after selecting it as the most critical in-plane axis. Applied loads were also reduced more than just the standard reduction from qualification to acceptance levels, to 10 g in sine and 6 g_{RMS} in random. All tests were performed under ISO-5 cleanliness requirements, and the behavior of the 15 tested units were remarkably consistent. For additional information on FM vibration test results, a dedicated paper is available [10].

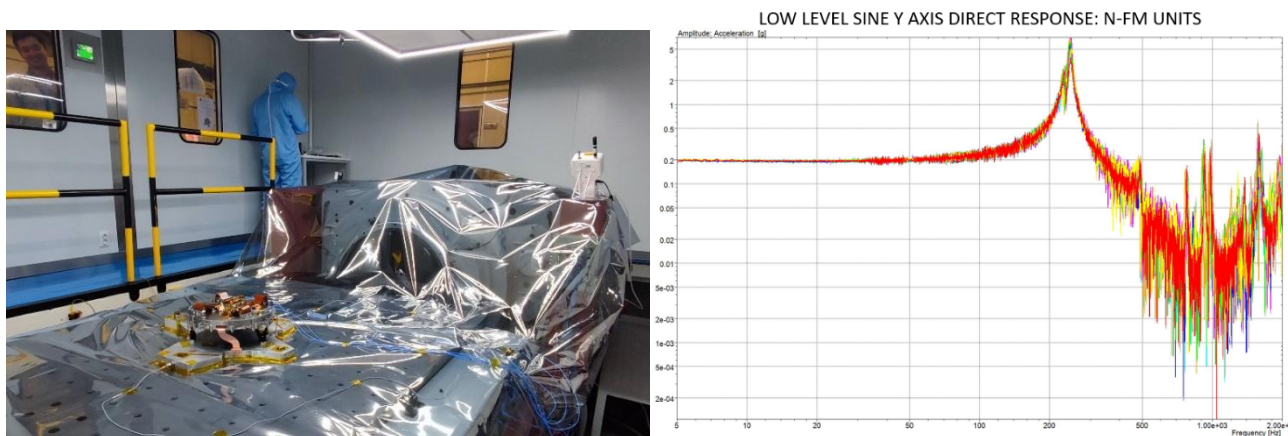


Figure 11. Flight model vibration ISO-5 test setup and all FM results comparison.

3. SUMMARY

The following tables summarize all the tests that have been performed and their mechanical and thermal levels applied on each of the different model test campaigns performed on PLATO FPA at INTA premises.

Table 3. Environmental test campaigns summary.

TEST	MODEL			
	Prototype	STM	QM	FM (x15)
Envelope	X			
Mass	X	X	X	X
CoG			X	
MoI	X	X	X	
Vibration	X	X	X	X
Shock	X			
Thermal Vacuum Cycling	X		X	
Thermal Balance	X			

Table 4. Mechanical and thermal test levels applied.

TEST	LEVELS		MODEL			
			Prototype	STM	QM	FM (x15)
Vibration	Sine Level [g]	X Axis	45	---	36.9	---
		Y Axis	50	---	39.6	9.9
		Z Axis	47	42.9	32.6	---
	Random Level [g _{RMS}]	X Axis	12.48	---	11.68	---
		Y Axis	11.32	---	11.75	5.87
		Z Axis	15.93	16.04	8.62	---
Thermal Vacuum Cycling	Non-Op. Temperatures		(-115 °C, +45 °C)	---	(-110 °C, +45 °C)	---
	Op. Temperatures		(-100 °C, -53 °C)	---	(-100 °C, -53 °C)	---
	N° Cycles		4 (3 Non-Op + 1 Op)	---	5 (4 Non-Op + 1 Op)	---

4. CONCLUSIONS

In the frame of PLATO FPA development, two major environmental test campaigns have been performed at INTA premises, the Prototype and the QM test campaigns, both of them including all the principal mechanical and thermal tests. This double qualification approach, with one full qualification being performed with wide margins and high load-levels in the early stages of the project, followed by the nominal qualification stage, made possible the reduction of the FM acceptance tests campaigns to a minimum, in order to meet the tight delivery schedule while still being confident in fulfilling all the requirements. A total of 15 FMs were tested at INTA premises and delivered within 2 years, proving that this validation strategy is valid for future missions with similar high-rate production and verification challenges.

ACKNOWLEDGEMENTS

Authors would like to note that the development of PLATO FPA has been feasible thanks to the deep collaboration within all parts involved in the PLATO Mission Consortium, from all different countries, and the technical teams at ESA.

The development of PLATO at INTA has been funded by the MICIN/AEI/10.13039/501100011033 grants PID2019-107061GB-C61, and MCIU/AEI and ERDF/EU grants PID2023-147338NB-C21.

REFERENCES

- [1] Rauer, H. et al, “The PLATO 2.0 mission”, *Experimental Astronomy*, (2014). <https://doi.org/10.1007/s10686-014-9383-4>
- [2] Rauer, H. et al, “The PLATO Mission”, arXiv:2406.05447 [astro-ph.IM], <https://doi.org/10.48550/arXiv.2406.05447>
- [3] Pajas, M. et al, “Focal Plane Assembly for PLATO Mission”, *IAF Space Systems Symposium, International Astronautical Congress (IAC), 2025*, Conference paper, <https://doi.org/10.52202/083091-0064>
- [4] Moreno, J. et al, “PLATO FPA. focal plane assembly of PLATO instrument”, *International Conference on Space Optics; ICSO 2018, Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series 11180*, 111803N (July 2019), <https://doi.org/10.1117/12.2536050>
- [5] G. Ramos et al, "Planetary transits and oscillation of stars (PLATO) focal plane assembly (FPA): prototype assembly and integration verification", *Proc. SPIE 11115, UV/Optical/IR Space Telescopes and Instruments: Innovative Technologies and Concepts IX*, 1111508 (9 September 2019); <https://doi.org/10.1117/12.2530549>
- [6] Isabel Vera et al, “Planetary Transits and Oscillation of Stars (PLATO) Focal Plane Assembly (FPA): Preliminary Model Philosophy and Prototype test results”, DOI: 10.13009/EUCASS2019-673, <https://www.eucass.eu/doi/EUCASS2019-0673.pdf>
- [7] Manjón, A. et al, “Focal plane assemblies for PLATO mission cameras: vibration test approach from prototype to serial-produced flight models”, *Optical Sensors 2025, Proc. of SPIE Vol. 13527*, 135271B · (2025), <https://doi.org/10.1117/12.3058516>
- [8] Santiago A. et al, “ESD Control at INTA in the Framework of the PLATO Mission: Since Subsystem Integration to CAMs Testing” *IAA Symposium on Safety, Quality and Knowledge Management in Space Activities, International Astronautical Congress (IAC), 2025*, Conference paper, <https://doi.org/10.52202/083095-0040>
- [9] Catalán I. et al, “Product Assurance Activities for PLATO Focal Plane Assembly”, *IAA Symposium on Safety, Quality and Knowledge Management in Space Activities, International Astronautical Congress (IAC), 2025*, Conference paper, <https://doi.org/10.52202/083095-0048>
- [10] Manjón, A. et al, “Focal Plane Assembly for PLATO 2.0 Cameras: Vibration Test Results Comparison in Serially Produced Flight Models”, *IAF Space Systems Symposium, International Astronautical Congress (IAC), 2025*, Conference paper, <https://doi.org/10.52202/083091-0065>