PLEIADES HR SATELLITE - MECHANICAL AND THERMAL ARCHITECTURE

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OVERVIEW

CNES is setting up a new optical high resolution system named PLEIADES HR. The system is based upon the use of a two satellite constellation, to propose a global coverage and a daily observation accessibility to any point on the Earth. PLEIADES HR system will provide high-resolution panchromatic (0.7 m) and multispectral (2.8 m) images with high quality in terms of resolution, MTF (0.2 at system level), and a high image location accuracy. The program represents a long term engagement with the introduction of newly European developed technologies.

The two Pleiades satellites developed by EADS Astrium as prime for the Satellite and by Thales Alenia Space as prime for the instrument, will be launched by Soyuz from Europe's spaceport in Kourou, French Guiana. (First Launch at the end of 2009). Both Instrument and Satellite CDR have been held. Assembly and integration activities are today in progress, the telescope is integrated and the alignment process is over.

The main design drivers for the mechanical architecture of the spacecraft are the pointing agility, the image location accuracy, the high thermo-mechanical stability to provide high resolution multispectral images and finally, the very compact and low-mass design, to make it compatible with a number of low-cost launch systems.

Agility requires a very compact design, hence, the imaging telescope is integrated inside the hexagonal platform; the solar arrays are fixed mounted at the top of the platform

Image location accuracy is achieved by minimizing the number of interfaces between the telescope and the relevant units of the Platform : the Star Trackers and the fibre-optic gyrometers are directly mounted on the main structure of the telescope

High thermo mechanical stability is optimised by using very low CTE materials for the telescope.

This paper describes Pleiades HR mechanical and thermal subsystem, the status of its development and all the measured or calculated performances.

1. PLEIADES HR MECHANICAL AND THERMAL ARCHITECTURE GENERAL DESCRIPTION

1.1. Design drivers

The main design drivers for this kind of Earth Observation satellite architecture are the image quality, the agility and the image location accuracy.

- The image quality drives the instrument size.
- A high agility requires a very compact design, with a few stiff appendages.
  As a consequence, the instrument is integrated inside the bus. The solar arrays panels are mounted directly on the bus structure without any drive mechanism, to ensure a maximum stability. Their first flexion mode frequency is increased by the use of stiffeners when deployed.
- A high image location accuracy is achieved by minimizing the interface between the instrument and the bus. The star trackers and the gyroscope heads are directly supported by the instrument to avoid any thermal distortion.

1.2. Satellite General Layout

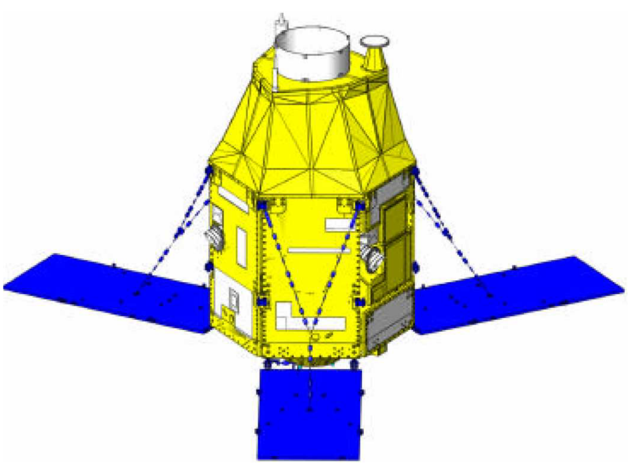

FIG 1. PLEIADES HR Satellite in orbit configuration

The high compactness and low mass of the satellite (<1000 kg) make it compatible with a large series of low cost small launchers (among them Soyuz and Rockot).

The bus structure is built on a hexagonal shape, with three solar arrays panels at 120 deg, and three star trackers in a quasi tetrahedron configuration, optimizing the attitude determination accuracy.

The Propulsion Module is mounted inside the bus structural central cone close to the launcher interface.

A specific antenna support structure is used to carry the Earth-pointing antennas and the instrument baffle.

All the electronic units are located on the lateral wall, as presented on the next figure

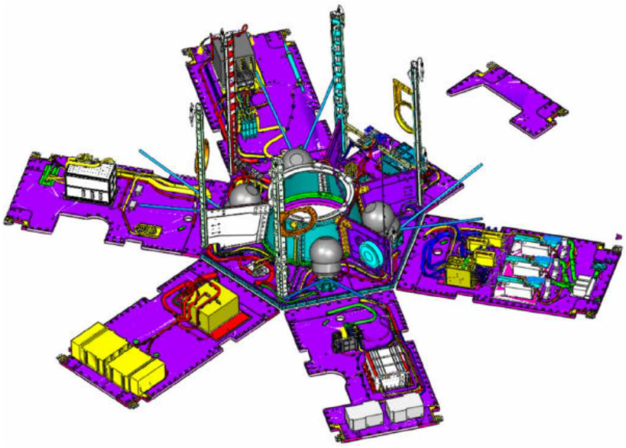

FIG 2. PLEIADES HR Bus lay-out

This configuration authorizes the accommodation of the instrument inside the bus: instrument bipods are fixed on the top of the central cone. It gives also the opportunity to optimize the instrument focal plane radiator location in term of heat dissipation.

The three star trackers and the gyroscope heads are directly mounted on the instrument primary structure to avoid any thermoelastic distortion that could be induced by the bus.

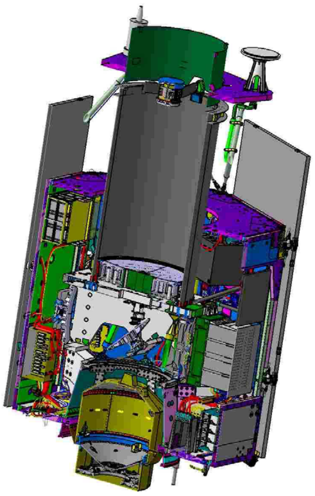

FIG 3. PLEIADES HR instrument interface

1.3. Satellite Primary Structure

The satellite primary structure is an hexagonal box constituted by aluminium sandwich panels.

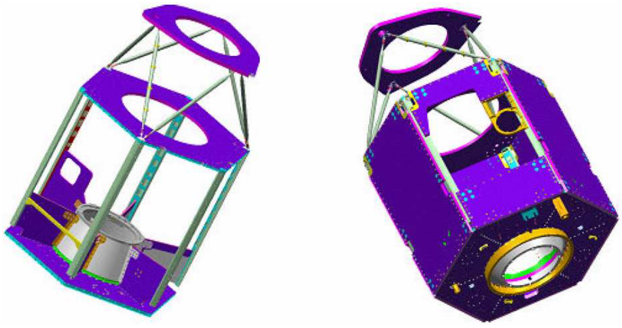

FIG 4. PLEIADES HR primary structure

The fixed part is made of the bottom panel, the central cone and the shear panels. The Lateral panels supporting most of the electronic units and the upper panel are integrated on it.

The bus structure mass is around 200 kg.

1.4. Instrument

The choices made for Pleiades instrument mechanical concept were driven by high stability requirements for all the optical equipment.

The mechanical architecture is also based on:

- the use of ultra stable materials for structure and mirrors
- the intensive use of isostatic interface for optics whose stability is sensible to interface displacements.

The instrument is divided into two areas:

- the rear area composed of the stiffened main panel on which are mounted all the equipment units: shutter mechanism, M1, M3 and reflecting mirrors and the focal plane with its video electronic unit,
- the front area composed of the carbon/ carbon tube and the M2 mirror subassembly.

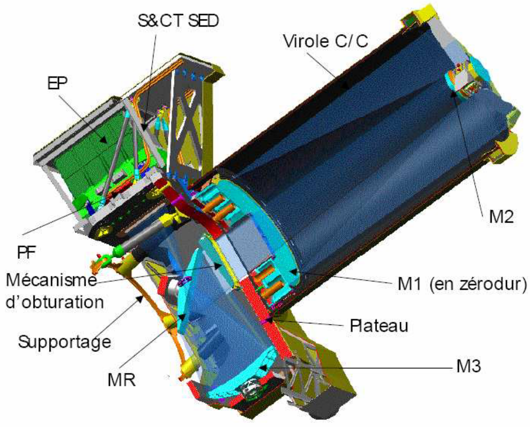

FIG 5. PLEIADES HR instrument

1.5. Thermal Control

Pleiades Satellite thermal control is divided into four parts

- Instrument
- Fine AOCS sensors (Star Trackers and Gyroscope)
- Bus electronic units
- Propulsion Module

Each of them is isolated from the others with MLI and insulating washers.
The optics and structures of the instrument are controlled at 23℃ for thermoelastic stability reasons. This i nvolves the platform units to be typically kept under 20 ℃

Next view shows the thermal passive control layout

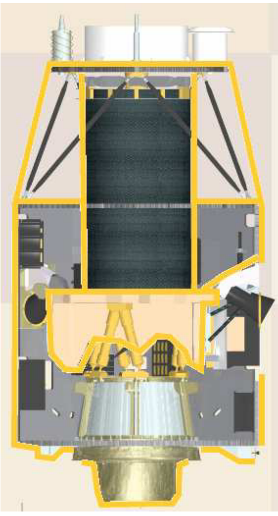

FIG 6. PLEIADES HR passive thermal control

In case of solar dazzling, the rear part of the instrument (focal plane in particular) is protected by the shutter mechanism. The front part is resistant to dazzling thanks to the implementation of specific coatings

2. MECHANICAL DESIGN AND QUALIFICATION

Pleiades satellite has been designed to be compatible with both Rockot and Soyuz mechanical environment, although selected launcher is today Soyuz. All specified levels are also envelopes of both Launch Vehicle specifications.

2.1. Quasi-static and Sine

2.1.1. FE Analysis

CD-Phase Finite Element analyses are based on very detailed models for the instrument (condensed model), the bus primary structure, the Solar Array, the Propulsion Module and the Control Moment Gyros.
All other units are modelled with concentred masses.

Satellite MEF mass is 1022kg, and COG location is calculated as follows: X=-22mm, Y=-11mm, Z=908mm.

Launcher rigidity specifications are fulfilled, the first calculated natural frequencies are about 18 Hz along the lateral axis, and 51 Hz along the longitudinal axis.

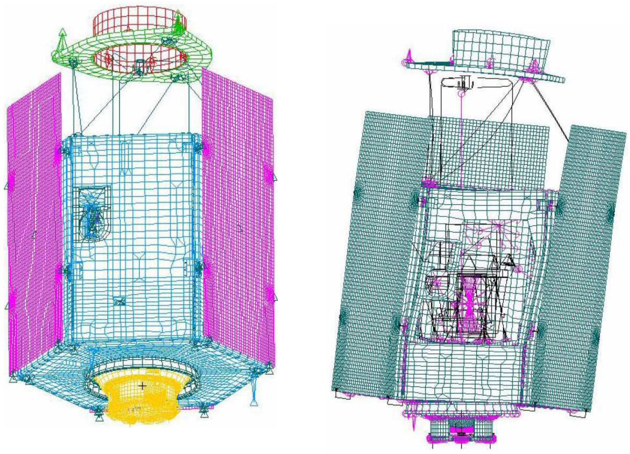

FIG 7. PLEIADES HR MEF – First lateral Mode @ 18Hz

Sine analysis is performed with the hypothesis of:

- Q-factor of 25
- Primary notch limited on -3.75g longitudinal and 2.34g lateral.

The calculated acceleration levels for the bus units are lower than 20g, excepted for the external antennas, for which the acceleration can reach 33g.

The calculated acceleration levels for the instrument internal components are lower than 25g.

2.1.2. Structural Model test campaign

Structure qualification for sine and quasi-static levels has been already reached by performing specific tests on a satellite Structural Model (SM).

SM is built with flight primary structure of Pleiades second satellite. It is equipped with mass representative mock-ups for the equipment and with Propulsion Module flight model.

A specific instrument mock up has been developed, which is representative of the main mechanical characteristics: mass, inertia, first natural frequencies.

The SM mechanical test campaign had the following objectives :

- To qualify the satellite flight primary structure
- To qualify the Propulsion Module flight model
- To validate the Finite Element satellite model
- To validate sine and QSL equipment specifications

The SM test was performed in April 2006. The test has brought to light several major elements:

- High Q-Factor on first satellite lateral modes (Q=75 to be compared with Q=25 for FE predictions)
- High damping ratio of the instrument mock-up because of what interface loads in instrument bipods have not been reached

FIG 8. PLEIADES Structural Model – Longitudinal test

Stifness objectives have been reached; the first satellite natural frequencies have been measured at 21 Hz (lateral) and 54 Hz (longitudinal) to be compared with Launcher specification at 15 Hz (lateral) and 35 Hz (longitudinal).

Qualification objectives of the SM test have been reached:

- Primary structure qualified for
  - Interface fluxes of 50 N/mm through a specific longitudinal quasi-static test @ 7.12g at the satellite interface (see FIG 8.), equivalent with 9.125g at COG (Rockot longitudinal specification is 10.125g)

Axe	Run	Date
Z	QSL05Z	27/04/2006

SWEEP RATE	FREQUENCY From	FREQUENCY To	LEVEL	TOLERANCES + ...dB	TOLERANCES -...dB
	20	23	7,12g	+2dB	-20 dB

Measurement Point	Notching (N) or Abort (A) value		FREQUENCES	NUMBER	PROFIL	TOL +dB
200Z	A	10g				

FIG 9. Structural Model – Z-QSL

  - Notched Sine levels as presented on the following curves

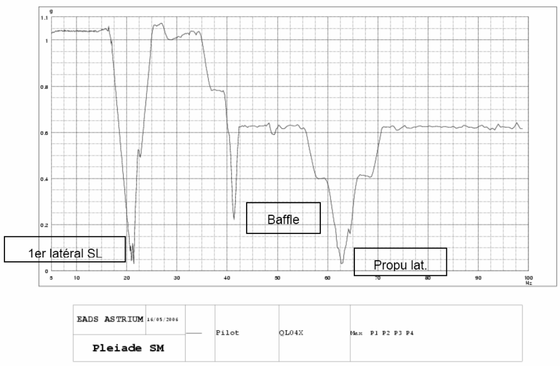

FIG 10. Structural Model – X Sine Qualification

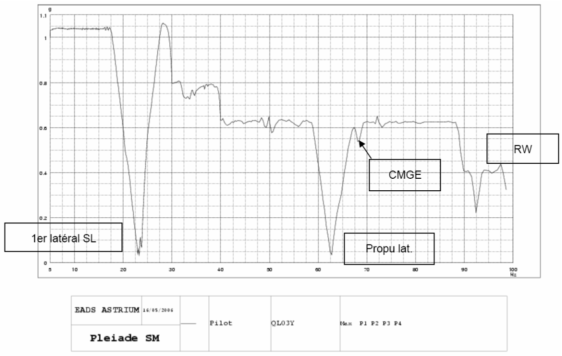

FIG 11. Structural Model – Y Sine Qualification

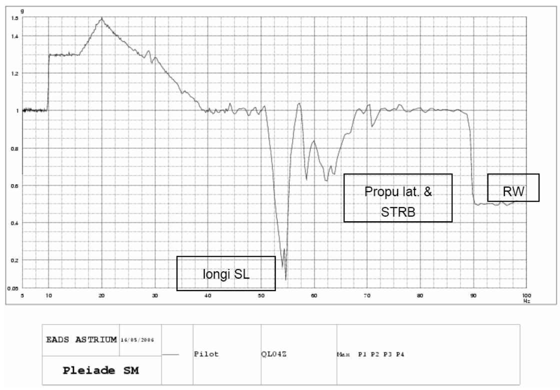

FIG 12. Structural Model – Z Sine Qualification

- Propulsion Module qualified with a lateral level of 4.85g to be compared with a Soyuz CLA predicted level of 4.47 g

Thanks to SM test campaign, Pleiades Satellite FEM has been updated with the following results:

Mode	FEM (Hz)	SM test (Hz)	Updated FEM (Hz)	Δf (Hz)
Lateral X	17.96	21.05	21.09	+0.04
Lateral Y	19.64	23.3	22.57	-0.7
Longitudinal	50.1	54.27	52.79	-1.5

TAB 1. Structural Model – Z Sine Qualification

2.2. Acoustic

Two Satellite acoustic analyses have been conducted with two different software: Rayon™ and Astryd™. Both analyses have led to very close results, from which the random specifications for all satellite units have been extrapolated.

Acoustic calculated responses are very low for all the units located inside the bus.

Nevertheless, the response on the secondary mirror, which is located at the top of the instrument is high, with a maximum DSP that reaches 4 g^2/Hz in the 180-200 Hz Band.

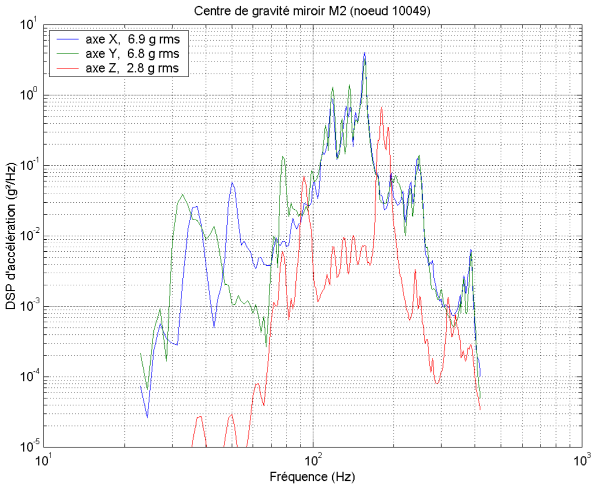

FIG 13. ASTRYD Acoustic Analysis - M2 Mirror responses

Insofar the instrument does not see any acoustic test at its level, sine environment will have to be adjusted during instrument sine qualification, to cover the acoustic stress distribution inside the instrument structure.

2.3. Shock

2.3.1. Launcher Clampband release

The exposed units to Launcher Clampband release shock environment are located close to Launcher Interface Ring (LIR):

- The 4 Control Moment Gyros, the Propulsion Module, the instrument power supply unit, The S-Band Antenna, which are directly bolted on the bottom panel,
- The 2 reaction wheels which are bolted on the shear walls,
- The instrument which is bolted on the structural cone.

The Launcher shock specification is based on the use of a low-shock clampband and is described on the next figure:

	Acceleration (g)
Frequency (Hz)	**Payload separation**
100	20
1500	1000
8000	2000
10 000	2000

TAB 1. Clampband release – Radial

	Acceleration (g)
Frequency (Hz)	**Payload separation**
100	10
300	25
1500	1000
10 000	2500

TAB 2. Clampband release – Longitudinal

All the units except the instrument have been qualified at their own level through a specific shock test or on satellites which have already been launched.

Instrument qualification is guaranteed through Finite Element analysis coupled with experience extrapolation:

- Finite Element analysis leads to maximum temporal expected acceleration at primary mirror COG of 25g, without any structural damping,
- Experience extrapolation allows to take into account a damping of 3 dB through the bus structure, and 6 dB through the telescope own interface bipods.

The expected QSL equivalent acceleration at mirror COG is also about 9g, to be compared with a 15g mirror QSL qualification level.

2.3.2. Solar Arrays Pyrotechnic shocks

Shock levels at satellite unit interface have been extrapolated for each of them by taking into account:

- Bus architecture to evaluate the damping of the primary structure
- Damping law which depends on the frequency band and on the distance between the pyrocutter and the unit
- A reference interface shock spectrum based on the experience from other programs.

To confirm these preliminary previsions, a specific shock test has been held on the satellite Structural Model. This test included:

- a dummy harness without electrical connectors connected to units,
- no solar arrays,
- no thermal hardware,
- no real units with their flexibilities, replaced by stiff aluminium dummies.

Therefore, the measurements are considered pessimistic and no additional margin is considered.

In addition most of the accelerometers are located in front of the shock source, with high shocks recorded considered as pessimistic compared to the average shock really seen by the unit interface.

The analysis of the shock measurements confirms the initial specifications to units. The comparison of the units qualification to the last set of shock requirements confirms that Pleiades is qualified with respect to the solar array pyro release shock, except for the Gyroscope and its electronic unit for which the qualification is still to come.

3. SATELLITE BUDGETS

3.1. Mass Properties

Satellite mass characteristics are presented in the following table

		PLEIADES HR Satellite
Mass	**(Kg)**	
Satellite		989
Instrument		215
COG location (Launch configuration)	**X (mm)**	1
	Y (mm)	5
	Z (mm)	920
Inertia @ COG (in orbit configuration)	**Ixx ($kg.m^2$)**	710
	Iyy ($kg.m^2$)	700
	Izz ($kg.m^2$)	450

TAB 3. PLEIADES HR Mass Budget

3.2. Image quality performances – Contribution to Instrument MTF budget

Stability of the Satellite and especially of the instrument contributes to the global satellite MTF budget.

The displacement of any optical element of the instrument contributes to degrade the image quality budget.

The contributors which are taken into account are of two types:

- On ground contributors
  - Alignment defaults due to mirror assembly and bonding
  - CCD interface flatness
- In flight contributors
  - 0g environment
  - Interfaces micro-sliding during launch
  - bus deformation due to bus thermo elastic deformation
  - Hygroelastic distortion
  - Instrument deformation due to Instrument thermo elastic deformation

The impact of each of them on the MTF stability budget is evaluated through Finite Element analysis. The global stability budget is obtained at the end thanks to a Monte Carlo calculation.

The following table gives the relative impact of each contributor to the MTF stability budget

		% of MTF stability budget
On ground	Alignment	2%
	CCD IF Flatness	8%
In Flight	0g	30%
	Micro-sliding	10%
	PF thermoelastic	5%
	Hygroelastic	10%
	Inst Thermoelastic	25%

TAB 4. MTF Stability Budget

MTF Instrument global budget is obtained by multiplying several major contributors, such as MTF stability budget, but also optical theoretical MTF budget, optics realisation MTF and CCD MTF.

Nevertheless, the impact of the optomechanical stability described above has a very limited impact on the MTF Instrument global budget, insofar as the instrument is equipped with a thermal focusing system on the secondary mirror which allows to adjust during flight the telescope focal distance.

3.3. Line of Sight stability

The contributors to the satellite line of sight stability are

- the instrument pointing accuracy under his own thermoelastic displacements
- the Star Sensors and their mechanical support pointing accuracy under their own thermoelastic displacements
- the Gyroscope pointing accuracy under his own thermoelastic displacements.

To evaluate these contributors, specific FEM calculations have been held. Results have been taken into account to build up the AOCS pointing budget.

The global results of FEM calculations are presented in the following table

	Seasonal Pointig accuracy
Instrument (µrad)	< +/- 1,5
Star Sensors (µrad)	< +/- 2
Gyroscope (µrad)	< +/- 2
Total (quadratic)	< +/- 3

TAB 5. Line of Sight Contributors

The impact of the satellite seasonal thermoelastic displacements on the line of sight stability is less than 4m on ground. Pleiades HR pointing accuracy is specified to be better than 10m.

4. CONCLUSION

Pleiades current Mechanical and Thermal activity has been concluded by the successful Satellite CDR in the second quarter of 2007.

The global Mechanical and Thermal data pack, which details the results presented in this paper has been judged acceptable.

Satellite assembly activities are now in progress. PFM qualification test campaign is foreseen for the first quarter of 2009, and the first launch of Pleiades HR Satellite will occur at the end of 2009.