CHEOPS Platform Thermal Architecture

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CHEOPS - CHaracterising ExOPlanet Satellite - is the first ESA's Science Programme of class S (Small mission) devoted to the observation and characterisation of nearby brilliant stars, already known to host exoplanets. CHEOPS Instrument will perform ultrahigh precision photometry to characterize the planetary systems with unprecedented precision. AIRBUS Defence & Space (Spain) is responsible for the system level design and assembly, integration and test activities, including the provision of the Platform. University of Bern (Switzerland) is in charge of the Instrument, which features a CCD detector in the focal plane of a 34 cm diameter on-axis telescope. The overall spacecraft is designed to fit within small launcher fairing volume (in dual launch configuration) with a mass not exceeding 300 kg. CHEOPS platform is based on a design-to-cost approach with maximum reuse of previous experience, such as SEOSAT, an Earth Observation satellite based on AS250 AIRBUS Defence and Space product line, featuring 3 deployable solar panels for a platform mass of 650 kg. CHEOPS hexagonal shaped platform is adapted to perform inertial pointing observations and is equipped with 3 body-mounted solar arrays. The total mass of the Platform is 220 kg. The main challenges regarding CHEOPS platform thermal architecture are: 1) To minimize flux exchanges between the Platform and the Instrument to achieve the very stringent requirements for instrument detector low temperature and thermal stability. 2) To accommodate several medium to high dissipative electronic units and ensure dedicated heat rejection capacity while minimizing heating power in both operational and safe modes. 3) To adapt SEOSAT existing thermal architecture (medium Platform, Nadir pointed, 6 walls available for radiators) to CHEOPS Platform specific constraints (smaller Platform, inertial pointing towards a wide range of targets, only 3 walls available for radiators because of the solar arrays). Platform thermal architecture is based on passive means (MLIs, radiators, Second Surface Mirror foils, thermal fillers…) complemented by an active heating system with a limited power consumption, which average orbital value is always kept below 20W during observation phases.

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Nomenclature

AIRBUS DS	=	AIRBUS Defence and Space
AOCS	=	Attitude and Orbit Control System
BAT	=	Battery
BCA	=	Baffle and Cover Assembly
BEE	=	Back-End Electronics
BOL	=	Beginning of Life
CCD	=	Charge-Coupled Device
CHEOPS	=	CHaracterising ExOPlanet Satellite
CIS	=	CHEOPS Instrument System
CoRoT	=	COnvection ROtation et Transits planétaires
CSW	=	Central SoftWare
EOL	=	End of Life
ESA	=	European Space Agency
FCV	=	Fuel Control Valve
FDV	=	Fill and Drain Valve
FEE	=	Front-End Electronics
FPA	=	Focal Plane Assembly
HTR	=	Heater
LCL	=	Latching current limiter
MAG	=	Magnetometer
MEPS	=	Myriade Evolution Proppulsion Subsystem
MGT	=	Magnetotorque
MLI	=	Multi Layer Insulation
MOC	=	Mission Operations Centre
OBC	=	On-Board Computer
OTA	=	Optical Telescope Assembly
PCDU	=	Power Control and Distribution Unit
RIU	=	Remote Interface Unit
RW	=	Reaction Wheel
SBT	=	S-Band Transceiver
SC	=	Spacecraft
SEM	=	Sensor Electronics Module
SOC	=	Science Operations Centre
SSM	=	Second Surface Mirror
STR-E	=	Star Tracker Electronics
STR-OH	=	Star Tracker Optical Head
TH	=	Thermistor
TMM	=	Thermal Mathematical Model
TM/TC	=	Telemetry/Telecommand
VDA	=	Vacuum Deposited Aluminum

I. Introduction

CHEOPS - CHaracterising ExOPlanet Satellite - will be the first mission in the frame of ESA Cosmic Vision programme dedicated to searching for exoplanetary transits by performing ultrahigh precision photometry on bright stars already known to host planets.

CHEOPS will provide the unique capability of determining radii within ~10% accuracy for a subset of those planets, in the super-Earth to Neptune mass range, for which the mass has already been estimated using ground-based spectroscopic surveys. CHEOPS will also provide accurate radii for new planets discovered by the next generation of ground-based or space transits surveys (from super-Earth to Neptune-size). By unveiling transiting exoplanets with high potential for in-depth characterisation, CHEOPS will provide suitable targets for future instruments suited to the spectroscopic characterisation of exoplanetary atmospheres.

Knowing where to look and at what time to observe makes CHEOPS the most efficient instrument to search for shallow transits and to determine accurate radii for planets in the super-Earth to Neptune mass range.

Table 1 below presents CHEOPS mission summary.

CHEOPS (CHaracterising ExOPlanet Satellite) Ultrahigh precision photometry of exoplanetary transits	
ESA Cosmic Vision Themes	What are the conditions for planet formation and the emergence of life?
Primary Goal	Characterise transiting exoplanets orbiting bright host stars
Targets	Known exoplanet host stars with V-magnitude ≤ 12 anywhere in the sky
Wavelength	0.4 to 1.1 μm
Orbit	Sun-synchronous, 650-800 km altitude, local time of ascending node: 06:00
Lifetime	3.5 years science operation (5 years goal)
Type	Small (S-class) mission

Table 1: CHEOPS mission summary

The CHEOPS mission is a partnership between Switzerland and ESA's Science Programme. The CHEOPS mission baseline relies completely on components with flight heritage. This is valid for the platform as well as for the payload components. For the former, it is an adaptation of the AS250 AIRBUS DS medium platform for Earth observation satellites. For the latter, the University of Bern team can exploit significant heritage from the CoRoT mission, minimising both cost and risk.

Launch readiness of CHEOPS is planned for 2018. The baseline scenario is a shared launch as auxiliary payload or co-passenger in Vega, or Soyuz or in another small launch vehicle.

The baseline orbit is Sun-synchronous, with an altitude in the range between 650 and 800 km and a local time of the ascending node of 06:00. This choice permits the rear of the spacecraft to be permanently Sun-pointed and is optimal for uninterrupted observations, and keeps thermal variations of the spacecraft and Earth stray light on the Instrument to a minimum as the orbital plane follows, as closely as possible, the day/night terminator.

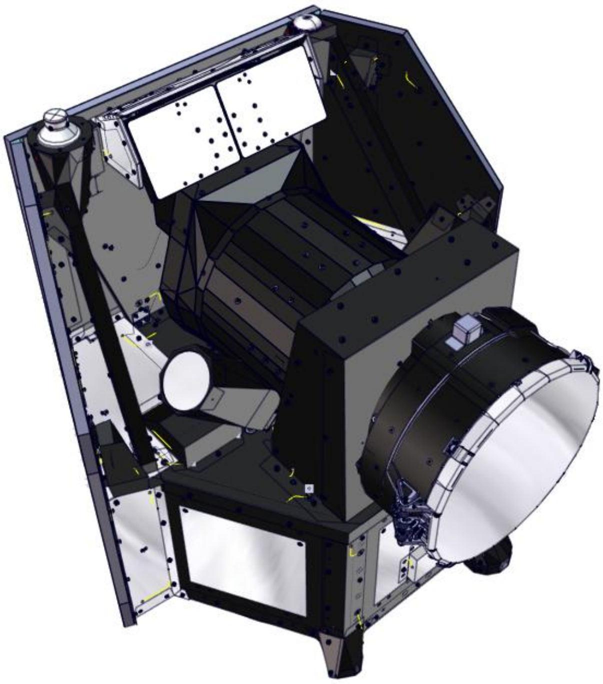
The data budget for CHEOPS is estimated at 1.2 Gb/day. An S-band system is baselined for data downlink, telemetry and telecommanding. A duration of 3.5 years for science operations is baselined to enable the execution of the proposed core programme, with an allocation of 20% of the observing time open to the whole scientific community.

Execution of the Low-Earth Orbit Phase (LEOP) and in-orbit commissioning will be performed by the spacecraft contractor, with an ESA-appointed flight director taking overall operation authority. Following the successful in-orbit commissioning of the spacecraft, responsibility for CHEOPS operations will be taken over by the CHEOPS Mission Consortium. The Mission Operations Centre (MOC) will be under the responsibility of Spain, while the Science Operations Centre (SOC) and the coordination of the Ground Segment will be located at the University of Geneva (Switzerland).

II. Spacecraft configuration

CHEOPS will be a small spacecraft with a total launch mass of approximately 250 kg. The baseline is to use a standard small satellite platform with some modifications. The spacecraft design was consolidated during the Phase A/B1 study, and Airbus DS Spain was selected as the platform provider.

Figure 1: CHEOPS spacecraft view



As illustrated in , CHEOPS has one single instrument. All platform requirements are aimed at supporting the functionality of the payload and its ultrahigh photometric precision. The main implications for the platform are related to pointing capabilities and the thermal environment for the payload.

The instrument and telescope is mounted on a stiff optical bench, which defines the interface to the platform, and is thermally decoupled. A sunshield mounted on the platform protects the focal plane radiator and detector housing from solar illumination and also carries solar panels for the power subsystem. When stowed for launch, the satellite measures about 1.5 m × 1.4 m × 1.5 m.

The spacecraft is three-axis stabilised, with a pointing stability of 8 arcsec rms over a 48-hour science observation. In a similar manner to CoRoT mission, the payload will provide centroid data from the target star to the platform's attitude and orbit control system, to enable compensation of low-frequency pointing errors.

During each orbit, the spacecraft will be slowly rotated around the telescope line-of-sight to keep the focal plane radiator oriented towards cold space, enabling passive cooling of the detector.

A. Instrument

To achieve its scientific objectives CHEOPS will be able to detect Earth-size planets transiting G5 dwarf stars (stellar radius of 0.9 R⊙) with V-band magnitudes in the range $6 \leq V \leq 9$ mag. Since the depth of such transits is 100 parts-per-million (ppm), this requires a photometric precision of 20 ppm (goal: 10 ppm) in 6 hours of integration time. The time interval corresponds to the transit duration of a planet with a revolution period of 50 days, and assumes an observation efficiency of 50%.

In the case of Neptune-size planets, CHEOPS will achieve a signal-to-noise ratio of 30 on such planets transiting K dwarf stars (stellar radius of 0.7 R⊙) with V-band magnitudes in the range $9 \leq V \leq 12$ (goal: $9 \leq V \leq 13$). Since the depth of such transit is 2500 ppm, this requires a photometric precision of 85 ppm in 3 hours, assuming an observation efficiency of 80% for a planet with revolution period of 13 days.

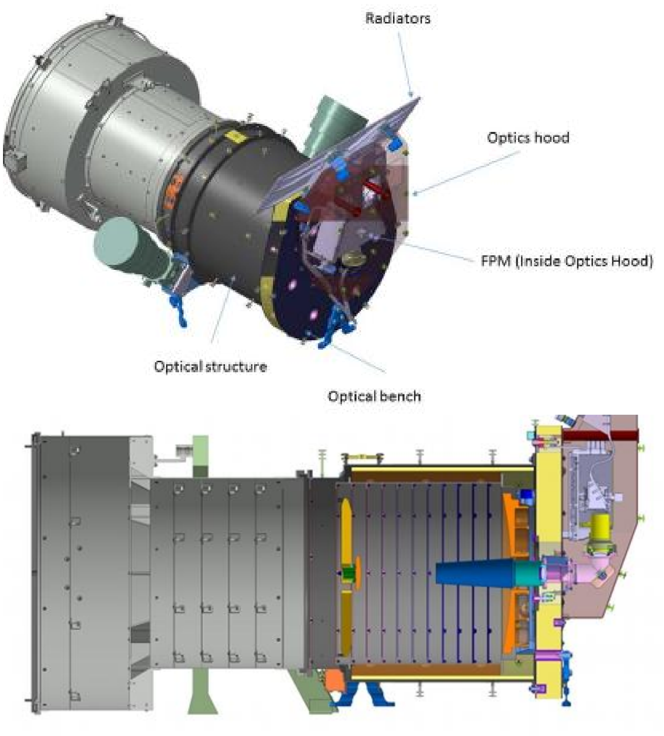
The required photometric precision will be achieved by using a single, frame-transfer, back-illuminated CCD detector with 1024 × 1024 pixels and a pixel pitch of 13 µm which is mounted in the focal plane of a ~32 cm diameter, f/8, on-axis Ritchey-Chrétien telescope. The detector will be passively cooled to < 233 K, with a thermal stability < 10 mK.

Stray light, primarily from the Earth, will be a major source of noise and the telescope must be baffled to control its impact. Cleanliness and contamination requirements lead to the need for a door cover which is light and dust tight. The detector plus support electronics together with the telescope, back-end optics, instrument computer and thermal regulation hardware are known collectively as the CHEOPS Instrument System (CIS).

The CIS is accommodated on the upper deck of the platform and comprises a number of units, as illustrated in Figure 2:

1. The Optical Telescope Assembly (OTA): this includes the telescope, the optical structure (mechanical support for OTA subsystems and the two star trackers), the back-end optics, the focal plane module (including the CCD, the focal plane array and front end electronics) and the two radiators which provide cooling for the focal-plane array as well as the front end electronics.
2. The Baffle and Cover Assembly (BCA): this includes the external baffle (axi-symmetric design) and the cover assembly, both mounted on the platform collar. The external baffle is designed to reject stray light from angles >35 degrees from the line of sight. The cover assembly is made up of a cover lid, which is found at the entrance aperture of the external baffle and designed to minimise contamination of the CHEOPS optics up to and including launch, and a cover release mechanism to be used after launch.

Figure 2: CHEOPS Instrument System overview



3. The Sensor Electronics Module (SEM): this comprises the sensor controller unit, used to control and read out the CCD, and the power conditioning unit used to condition/filter the voltages supplied to the CCD and to the CCD and front-end electronics thermal control. This unit is accommodated inside the Platform.
4. The Back-End Electronics (BEE): this comprises the digital processing unit and the power supply unit that provides the power for all elements of the CIS. This unit is accommodated inside the Platform.

B. Platform

The platform is based on the recurrent use of the flight proven AS250 architecture (hardware and software) to optimize overall cost, secure planning and reduce risks, however the mission characteristics allows to use smaller or less complex equipment to save mass and cost.

CHEOPS mechanical architecture is designed considering launcher mass and volume criteria, with the objecive to allow launcher combinaion opions as piggy-back or co-passenger for the reference launch vehicles (Vega, Soyuz, PSLV, DNEPR) to enable a cost-effecive launch.

The platform is equipped with three body-mounted solar array panels, at 60 degrees between them, offering best illumination in any mission attitude. The central solar array panel provides support for the fixed sunshield, made out of MLI, that provides shadow to the instrument radiators all along the mission.

The AOCS design features a simple scheme of three modes: Acquisition and Safe Hold mode, Normal Mode and Orbit Control Mode. Attitude control is performed by the reaction wheels, including reorientation to science targets and roll slews. Orbit control uses a propulsion module inherited from AS250 with minor modifications to accommodate a smaller tank, allowing nevertheless the highest specified altitude (800 km), which benefits the observability of the mission.

CHEOPS baseline design takes into account the reuse of the AS250 HYDRA star tracker, which will be used along with the instrument-in-the-loop, achieving with its nominal behaviour an Absolute Pointing Error of less than 4 arc seconds during observation phase.

The communication equipment includes nominal and redundant S-Band transmission and recepion chains. The downlink enables to transmit 2 Gbits per day. An uplink at 4 Kbps offers a fast link to ensure high commanding capability.

CHEOPS power architecture is based on the reuse of AS250 Power Control and Distribuion Unit (PCDU) and a down-sized Li-ion battery. The power distribuion is protected by means of nominal and redundant current limiters, to avoid units damage and unnecessary power consumpion.

III. Platform Thermal Architecture

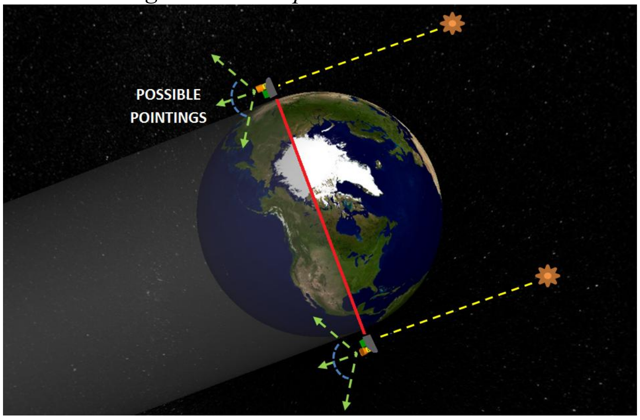
CHEOPS thermal architecture has been conceived to provide the thermal environment (temperature ranges, temperature gradients, and temperature stability) to ensure the full required performances for each mission phase and operational mode and for the complete duration of the mission.

In particular, payload stability requirements are very stringent and thus drive the attitude along the observations and the overall thermal design, so to minimize perturbations on instrument radiator temperature.

Thermal control design drivers are linked to the payload required attitude during observation phases.

- Instrument Line Of Sight (+X SC axis) shall be inertially pointed to the target star, and anti-Sun pointed. The Sun exclusion angle restriction is limited to +/-60º. Therefore, the Sun can illuminate +/- Y panels with a maximum incidence of 60º.
- Instrument radiator (+Z SC axis) not facing the Earth. The SC shall roll around X axis to avoid instrument radiator in view of IR and albedo fluxes. Therefore, the Sun can illuminate +/- Z panels with a maximum incidence of 60º .

Figure 3. CHEOPS Nominal Attitude Definition. *Thermal control design drivers are linked to the payload required attitude during observation phases.*



Platform sunshield prevents the sun to illuminate instruments radiator under any observation condition. Heat flux coming from the platform onto the instrument radiator must be minimised. Instrument (except BEE and SEM units) and platform are designed to be thermally decoupled (radiatively and conductively). Radiative insulation is achieved by mean of MLI covering both instrument telescope and platform top floor panel and solar arrays rear side (in view of the instrument). Conductive decoupling is achieved via low conductive attachment (thermal washers) of the instrument to the top floor panel.

Instrument electronic units BEE and SEM are installed inside the platform under the platform thermal control responsibility, so their thermal design relies on the same principles than the rest of the units inside the platform.

Platform thermal design main purposes are:

- Providing the payload with appropriate thermal interfaces, in terms of temperature, gradients, temperature stability and heat flux exchange, as per instrument requirements.
- Providing equipments inside the platform with appropriate insulation from external environment, so as internal dissipation rejection capability, in order to maintain them within their design temperatures ranges.

Platform and instrument units and interfaces design temperature limits and equipment dissipations, are recalled in next table.

CHEOPS platform is based on AS250, the Airbus DS generic medium-size platform for earth observation satellites. Thermal architecture has been adapted to CHEOPS mission specific needs and observation constraints, always re-using AS250 heritage, as much as possible, in terms of thermal hardware and thermal design solutions.

Table 2. CHEOPS Temperature design limits & Equipment dissipation

UNIT	DESIGN LIMITS (ºC)					DISSIPATION (W)		
	OPERATING		NON OPERATING		SWITCH-ON			
	T MIN	T MAX	T MIN	T MAX	T MIN	NOMINAL	SAFE MODE	LEOP
RW	-20	60	-20	60	-20	2.7x4	0.85x4/2.7x4 (10)	OFF
PCDU	-20	50	-30	60	-30	53/38 (3)	53/38 (3)	45/38 (3)
OBC	-20	50 (8)	-30	60	-30	21	21	21
MAG	-15	45	-30	60	-30	0 x 2	0.9 x 2	0 x 2
STR-E	-20	55	-30	60	-30	12.1 x 1	OFF	OFF
RIU	-20	50	-30	60	-30	31	40/31 (10)	29,2
SBT	-20	50	-30	60	-20	4.7/14.7 (1)	4.7/14.7 (1)	4,7
BAT	10 (7)	30	-20	40	-20	0/4.85 (3)	0/4.85 (3)	0/4.85 (3)
MGT	-25	60	-40	70	-35	0.2 x 3	2 x 3	0 x 3
S-BAND ANT	-100	95	-100	95	NA	0/0.14	0/0.14	0
STR-OH	-25	60	-30	60	-30	Acc to TMM	OFF	OFF
PM TANK	10	50	10	50	NA	-	-	-
PM FILTER	10	50	10	50	NA	-	-	-
PM PR TRANSD	10	50	10	50	NA	0,43	0,43	0,43
PM LATCH VALVE	10	50	10	50	NA	-	-	-
PM FDV	10	50	10	50	NA	-	-	-
PM THRUSTER FCV	10	90 (2)	10	50	NA	-	-	-
BEE	-20	50 (9)	-30	60	-30	14,6	OFF	OFF
SEM	-20	35 (9)	-30	60	-30	3,9	OFF	OFF
FPA	-50	30 (4)	-65	50	-65	0,3	OFF	OFF
FEE	-20	30 (5)	-50	50	-30	7,5	OFF	OFF
TELESCOPE	-15	0 (6)	-50	50	-30	-	-	-
OTA SRP	-20	50	-30	60	NA	-	-	-
BCA SRP	-65	50	-80	60	NA	-	-	-

(1) Dissipation Rx/Tx
(2) During Firing
(3) Dissipation day/eclipse
(4) Controlled @ -40ºC +/- 10mK
(5) Controlled @ 2ºC +/- 50mK
(6) Controlled @ -10 +/- 5ºC
(7)Optimum range 20 +/-5ºC. +15ºC on Safe Mode due to current limitation
(8) Controlled @ 22ºC -0/+3ºC for Nominal Observations
(9) Stability > 10K
(10) Transition / Stabilized

In order to achieve the objectives detailed in the previous paragraph, passive thermal control elements are mainly implemented.

- MLIs are used to provide insulation from the external environment.
- Radiator foils are bonded to Platform cold panels (+X side) to allow rejection of the heat dissipated by electronic units.
- Radiator foils are also used to close the gap between the Solar Array and the Platform Primary structure, to avoid solar trapping inside the cavity and to increase the heat rejection capability of the Platform.
- Black coatings are applied to lateral panels and internal units to increase the radiative coupling inside the Platform.
- Interface fillers are used to increase the thermal contact with the mounting panel of those units in which their dissipation needs to be rejected by conduction.
- Thermal washers are used to conductively decouple from the mounting panel those units in which their dissipation needs to be rejected by radiation.

Active thermal control (foil heaters and temperature sensors) are also used to maintain all the equipment above their minimum design temperature during cold phases (eclipses or SC modes when units are not operating), so as to maintain the required stability performances. Non-operating heaters (survival) for the Instrument are also controlled by the platform.

CHEOPS thermal architecture is presented in Figure 4 and Figure 5. Insulation from external environment is provided by mean of MLI, covering all the surfaces not used as radiators. Black Kapton MLI is proposed in order to avoid any solar reflexion in any operation mode.

The rear side of the Solar Array Central & Lateral panels will be covered with Black Kapton MLI in the area not in front of the SC Lateral panels (upper area).

Figure 4. CHEOPS Platform Thermal Architecture Description (I)

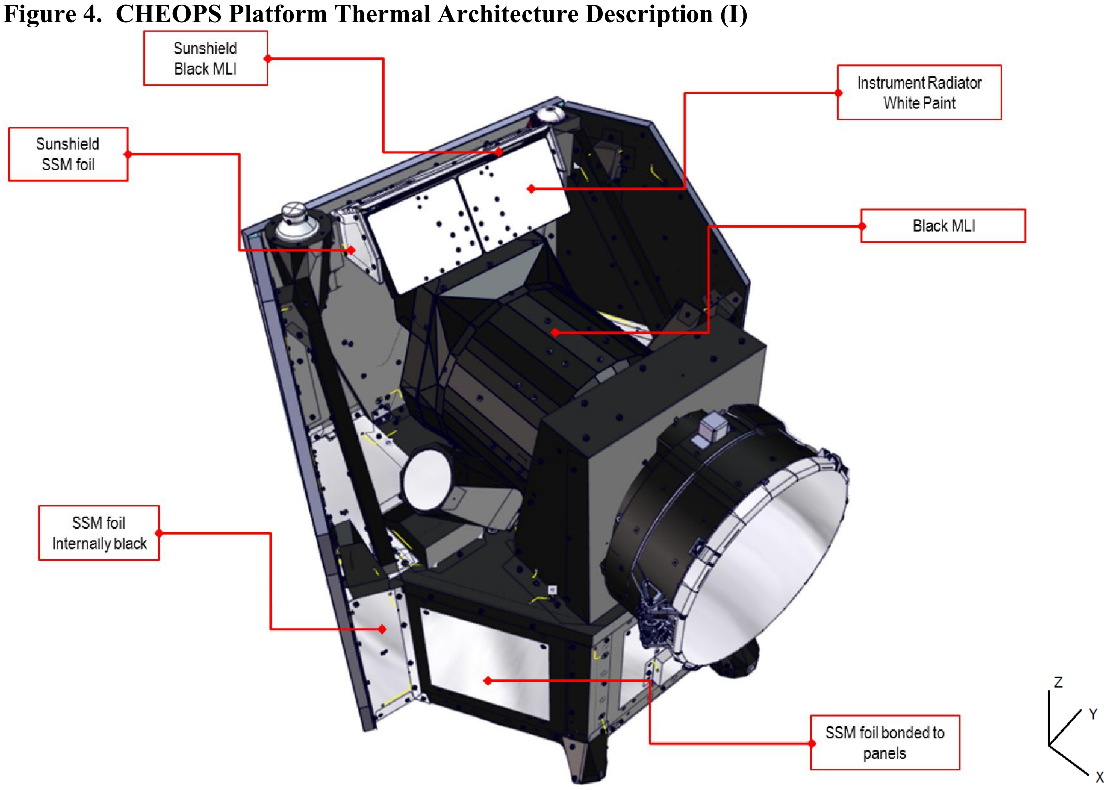
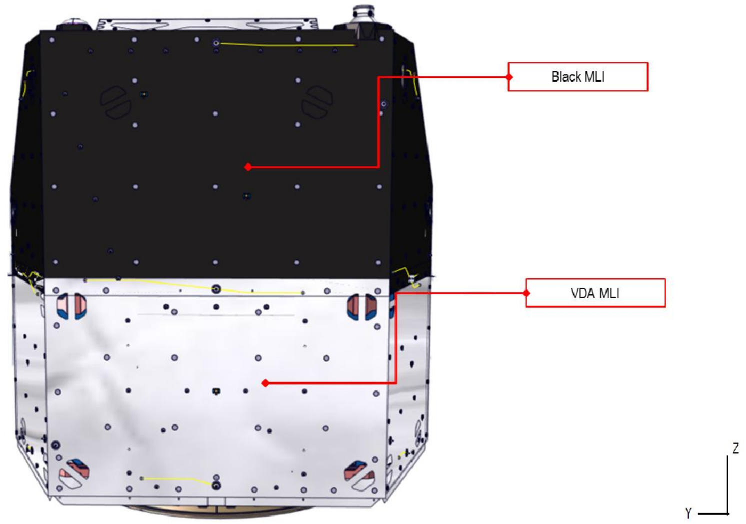


Figure 5. CHEOPS Platform Thermal Architecture Description II

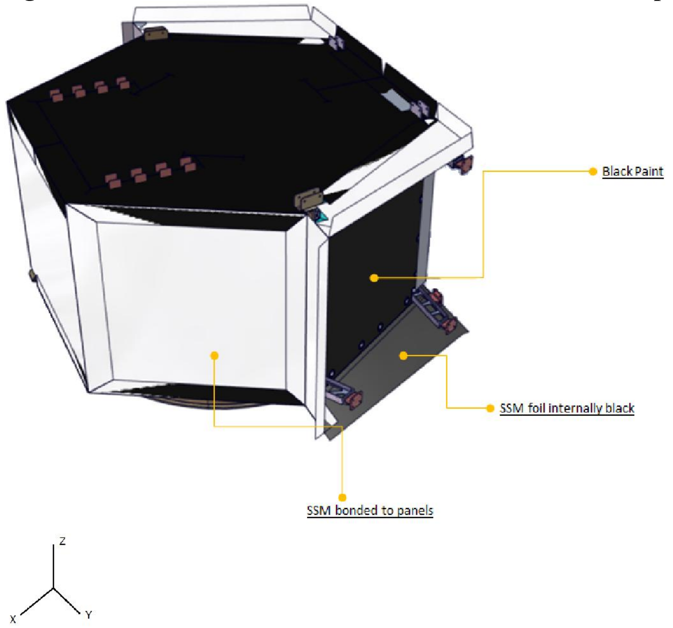


Solar Array Central & Lateral panels rear side will be covered with VDA Kapton MLI in the area in front of platform panels (lower area). The reason for using VDA Kapton MLI (emissivity 0.05) is to ensure a complete radiative decoupling between the Solar Array rear side (hot) and the lateral panels in front of them, guarantying the heat rejection path as explained in Figure 8.

The external side of –X Platform Lateral panel will also be covered with VDA Kapton MLI to increase the insulation between SC and Solar Array Central panel.

Top & Bottom Platforms will also be isolated (from the external environment and from the payload) by mean of Black MLI, in order to keep the instrument interfaces at the requested temperature range. Star Tracker Optical Heads, S-Band antenna brackets and secondary support structure for Solar Array will also be covered with Black Kapton MLI. BCA support structure for interface between instrument and platform will be covered by Black Kapton MLI, as the rest of the telescope.

Figure 6. CHEOPS Platform Thermal Architecture Description III



Platform Lateral panels in view to the space (+X, +X-Y & +X+Y panels), will be used as radiators. SSM (Silver Teflon) foils will be bonded to these panels.

The cavity between the Lateral Solar Array wings and the platform –X+Y & +X+Y panels will also be used to re-radiate the heat dissipated by the equipment mounted on these panels, increasing considerably the available radiator area, and therefore the platform heat rejection capability.

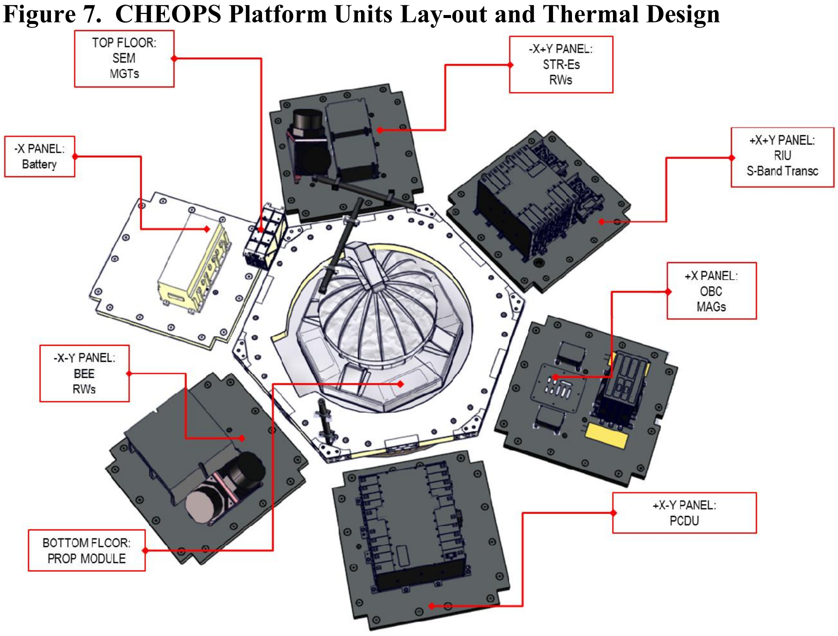
Platform –X+Y & -X-Y Lateral panels will be externally black painted, and the gap will be closed with SSM foil internally black (Black Kapton x Silver Teflon) extended also over Top platform panel. Black Kapton internally (high emissivity) radiatively collects the heat dissipated by the units and Silver Teflon externally (high emissivity, low absorptivity) rejects this heat to the space.

Units have been accomodated in order to allow a proper evacuation of the dissipated heat.

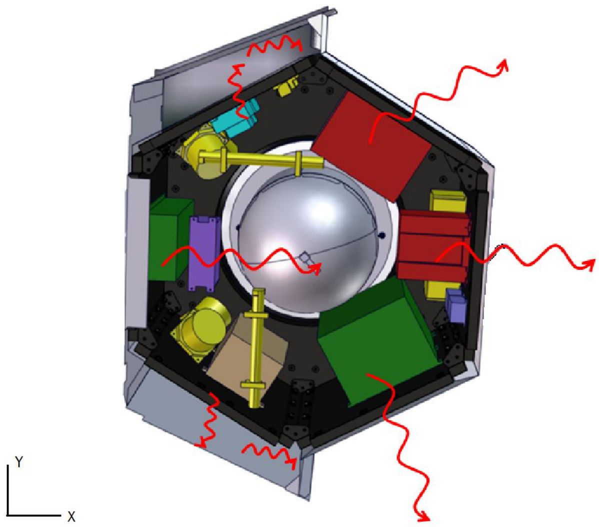
Due to the SC attitude during observations, +X, +X-Y and +X+Y lateral panels are the coldest panels, therefore, the most dissipative units have been mounted in them (OBC, PCDU and RIU). Units located in these panels will be mounted with thermal interface filler (Cho-therm) to increase the contact coupling with the radiator panels.

-X lateral panel is the hottest one, due to the presence of the Solar Array central panel (always sun illuminated). So, the Battery has been accomodated in this panel, as this unit will only be dissipating heat during eclipses (short periods in concrete epochs of the year around the winter solstice). Battery will be mounted with thermal washers (glass fiber) to the panel in order to conductively decouple the unit.

Figure 7. CHEOPS Platform Units Lay-out and Thermal Design



Units accomodated on –X-Y and –X+Y lateral panels reject their dissipation by radiaton to the cold panels and by re-radiation to the space through the foils closing the gap between primary structure and solar array. This heat rejection way is not as efficient as the direct radiation to space, so, intermediate-low dissipative units are accomodated in these panels. As these units are using both radiation to the internal environment and conduction to the mounting panel heat transfer methods, they are mounted with interface filler to the lateral panels.

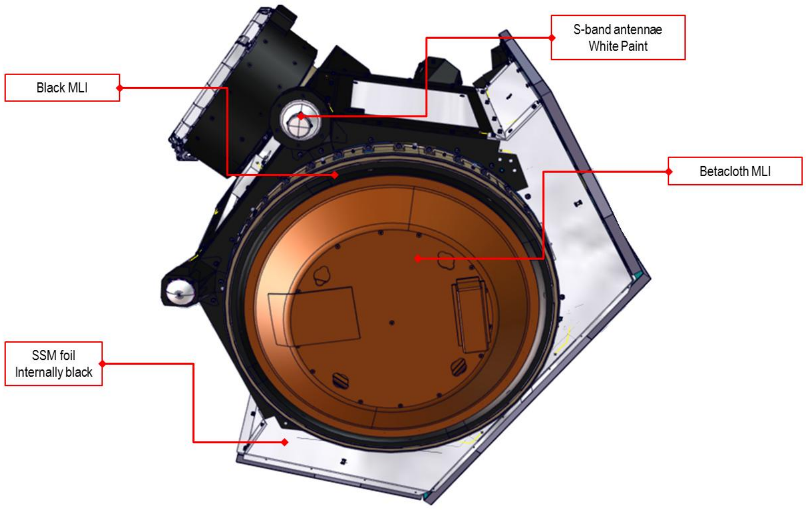


Magnetotorques (MTQ) and Magnetometers (MAG) accomodation is driven by EMC constraints regarding their relative location and their location wrt the battery, and room availability. MTQs and MAGs are very low dissipative units with large design temperature range, typically designed to dissipate their internal heat by radiation, and they are mounted with thermal washers.

SEM unit accomodation is restricted by the harness length between the unit and the instrument OTA, so, it needs to be located on the Top Floor panel, with interface filler.

All the units are black coated, either black painted or black anodized, with a minimum infrared emissivity of 0.8, and so are the panels internally, in order to guarantee an internal temperature homogeneity and radiation flux exchange within the platform internal cavity. Exceptions are the –X panel (in which the battery is mounted) and the Bottom Floor panel (attached to ring for launcher interface), as these are hot panels due to the coupling with the Solar Array and the IF Ring. These two panels will be internally Alodine, as well as the battery and SEM units.

Figure 9. CHEOPS Platform Thermal Architecture Description IV



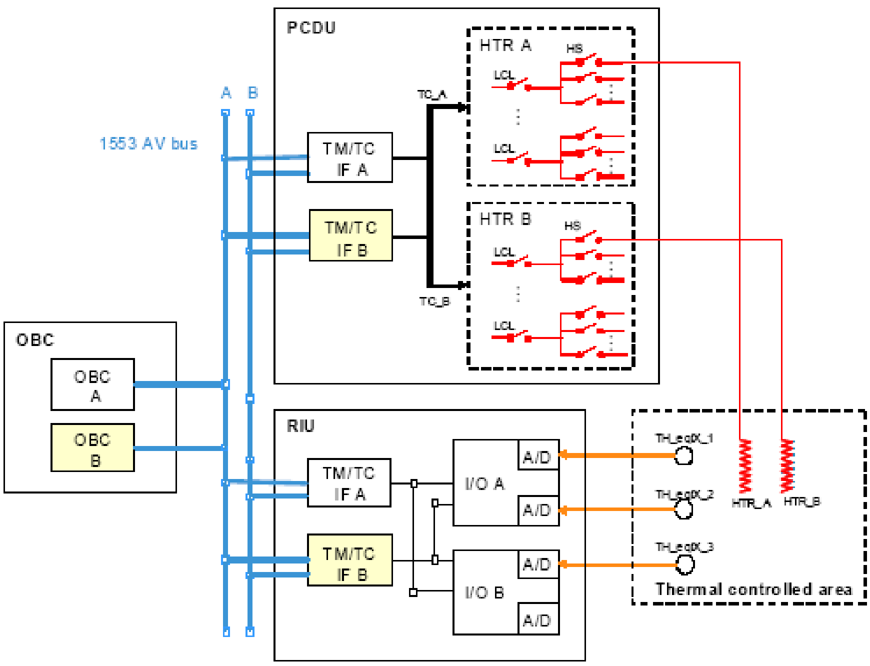
Propulsion module for CHEOPS is recurrent for Myriade Evolution, and is based on PM22 for AS250 (Airbus DS generic platform for earth observation) with the tank down-sized to CHEOPS envelope, and the fill and drain valves relocated in the bottom side of the platform. The thermal control design is heritage from the PM 22 and is an integral part of the propulsion subsystem. Tank and propulsion platform are surrounded by a tent-like VDA MLI to decouple them from the rest of the platform internal enclosure, as they work at different temperature ranges. Propulsion module is installed on the Interface ring, at 8 points, conductively decoupled by mean of thermal washers.

Star Tracker Optical Heads are mounted on the instrument bipods with thermal washers. They are covered with Black Kapton MLI up to the baffle extremity. No dedicated radiators are foreseen, as the solar and earth flux inside the optical heads baffles is very limited due to their orientation and SC attitude for observations. Thermal analyses reported in this document confirm that optical heads thermal performances are properly achieved w/o dedicated radiators.

S-Band antennae will be mounted on both +Z and –Z sides (4 antennae will be mounted, 2 Tx and 2 Rx). Antennae will be white painted and the supports for attachment to +Z secondary structure for solar array support, and –Z propulsion platform will be MLI covered.

The sunshield will be a fix MLI supported and attached to the Solar Array supporting structure by mean of light supports. The external layer of the sunshield (facing the sun) will be a Silver teflon foil in order to reduce the solar flux absorption, whereas the internal side (facing the instrument) will be a black MLI, in order to avoid any reflexion of the solar flux.

Figure 10. CHEOPS Platform Heating System Architecture



Heating lines will be installed to compensate equipment dissipation in the mission phases when they are OFF and in cold phases (eclipses), in order to maintain them at their minimum requested temperature, or to maintain requested stability performances.

The specific thermal control of the instrument in nominal mode is performed by the CSW payload application but the thermal regulation is controlled by the platform software when the payload is OFF (survival mode).

The thermal control is made on 17 thermal lines (from the 36 available heating lines at the PCDU). From these 17 heating lines, 7 are dedicated to the propulsion module and 6 are dedicated to the instrument for safe mode (instrument OFF). Each thermal line is controlled independently: one thermal line regulates the temperature of one physical area, with three thermistors (the median value is used for the control) and one (or several) redundant heater(s). When several heaters are affected to one given area, they are powered through a single PCDU line. The system is fully redundant.

A coarse thermal regulation (ON/OFF), controlled every 10 seconds, is sufficient in case of CHEOPS platform thermal control.

Heaters and thermistors location are identified in next tables. Double layer Kapton foil heaters are foreseen (nominal & redundant circuits in the same heater) when available space is limited.

Table 3. CHEOPS Platform Heating System Architecture

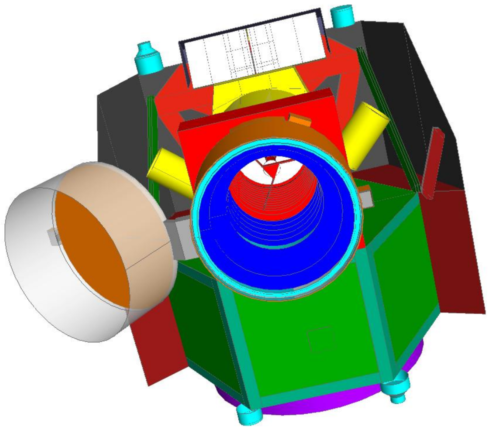
PRIME HEATING LINE		HEATING LINE						CONTROL THERMISTORS		
NUMBER	NAME	THRESHOLD (ºC) NOMINAL		THRESHOLD (ºC) SAFE MODE		POWER (W) @27V	RESISTANCE (Ohm)	LOCATION	IDENTIFICATION 3 (A,B,C)	TYPE
		ON	OFF	ON	OFF					
HL01A	Battery_N	14.0	15.0	19.0	20.0	2.9	250.0	Battery TRP	TH_BATT_A-B-C	ANF
HL04A	STR_OH_1_N	-9.0	-8.0	-19.0	-18.0	4.0	182.3	STR OH +Y Base	TH_STR_OH1_A-B-C	ANF
HL26A	STR_OH_2_N	-9.0	-8.0	-19.0	-18.0	4.0	182.3	STR OH -Y Base	TH_STR_OH2_A-B-C	ANF
HL24A	OBC_N	22.0	23.0	-10.0	-9.0	30.0	24.3	OBC TRP	TH_OBC_A-B-C	ANF
HL06A	PM: Tank_N	18.0	20.0	18.0	20.0	4.7	155.0	Tank	TH_PMTANK_A-B-C	ANF
HL13A	PM: Vertical_Plate_L1_N	18.0	20.0	18.0	20.0	16.9	43.0	Prop vert plate	TH_PMVP_A-B-C	ANF
HL27A	PM: Vertical_Plate_L2_N	18.0	20.0	18.0	20.0	16.9	43.0			
HL18A	PM: FCV Heater Thruster1_N	18.0	20.0	18.0	20.0	0.5	1568.0	Thruster 1 FCV	TH_PMFCV1_A-B-C	ANF
HL12A	PM: FCV Heater Thruster2_N	18.0	20.0	18.0	20.0	0.5	1568.0	Thruster 2 FCV	TH_PMFCV2_A-B-C	ANF
HL02A	PM: FCV Heater Thruster3_N	18.0	20.0	18.0	20.0	0.5	1568.0	Thruster 3 FCV	TH_PMFCV3_A-B-C	ANF
HL21A	PM: FCV Heater Thruster4_N	18.0	20.0	18.0	20.0	0.5	1568.0	Thruster 4 FCV	TH_PMFCV4_A-B-C	ANF
HL03A	CIS_Survival_Telescope_N	-30.0	-25.0	-30.0	-25.0	20.0	36.5	CIS Telescope	TH_CIS1_A-B-C	ANY
HL30A	CIS_Survival_FEE_L1_N	NA	NA	-15.0	-10.0	13.0	56.1	CIS FEE structure	TH_CIS2_A-B-C	ANY
HL36A	CIS_Survival_FEE_L2_N	NA	NA	-15.0	-10.0	13.0	56.1			
HL29A	CIS_Survival_FPA_L1_N	NA	NA	-45.0	-40.0	6.0	121.5	CIS FPA cold block	TH_CIS3_A-B-C	ANY
HL33A	CIS_Survival_FPA_L2_N	NA	NA	-45.0	-40.0	6.0	121.5			
HL09A	CIS_Annealing_N	NA	NA	40.0	50.0	30.0	24.3			

PRIME HEATING LINE		HEATERS						
NUMBER	NAME	LOCATION	QTY	CIRCUIT LAYOUT	RESISTANCE (Ohm)	TYPE	RESISTIVE CIRCUIT SIZE (mm)	
							length l	width w
HL01A	Battery_N	Battery internal	1+1	NA	250.0	single layer	100	30
HL04A	STR_OH_1_N	STR OH +Y Base	1	NA	182.3	double layer	40	40
HL26A	STR_OH_2_N	STR OH -Y Base	1	NA	182.3	double layer	40	40
HL24A	OBC_N	Panel close to OBC	2	//	48.6	double layer	150	60
HL06A	PM: Tank_N	Tank	4	//	620.0	double layer	200	25
HL13A	PM: Vertical_Plate_L1_N	Prop vert plate	4	//	172.1	double layer	100	40
HL27A	PM: Vertical_Plate_L2_N	Prop vert plate	4	//	172.1	double layer	100	40
HL18A	PM: FCV Heater Thruster1_N	Thruster1 FCV	1	NA	1568.0	double layer	60	20
HL12A	PM: FCV Heater Thruster2_N	Thruster2 FCV	1	NA	1568.0	double layer	60	20
HL02A	PM: FCV Heater Thruster3_N	Thruster3 FCV	1	NA	1568.0	double layer	60	20
HL21A	PM: FCV Heater Thruster4_N	Thruster4 FCV	1	NA	1568.0	double layer	60	20
HL03A	CIS_Survival_Telescope_N	CIS Telescope	2	//	73.1	double layer	545	80
HL30A	CIS_Survival_FEE_L1_N	CIS FEE capacitor	1	NA	56.1	ceramic	20	15
HL36A	CIS_Survival_FEE_L2_N	CIS FEE capacitor	1	NA	56.1	ceramic	20	15
HL29A	CIS_Survival_FPA_L1_N	CIS FPA capacitor	1	NA	121.5	ceramic	20	15
HL33A	CIS_Survival_FPA_L2_N	CIS FPA capacitor	1	NA	121.5	ceramic	20	15
HL09A	CIS_Annealing_N	CIS FPA capacitor	1	NA	24.3	ceramic	20	15

IV. Spacecraft Thermal Analysis

To determine the thermal performances of CHEOPS spacecraft, a Thermal Mathematical Model has been built, representing the SC with its relevant thermal properties, in order to compute the temperatures, radiative couplings and fluxes for CHEOPS mission. S/C TMM includes instrument detailed TMM, propulsion module detailed TMM and Star Tracker Optical Head detailed TMM, as well as units reduced TMMs.

Figure 11. CHEOPS SC TMM Overview

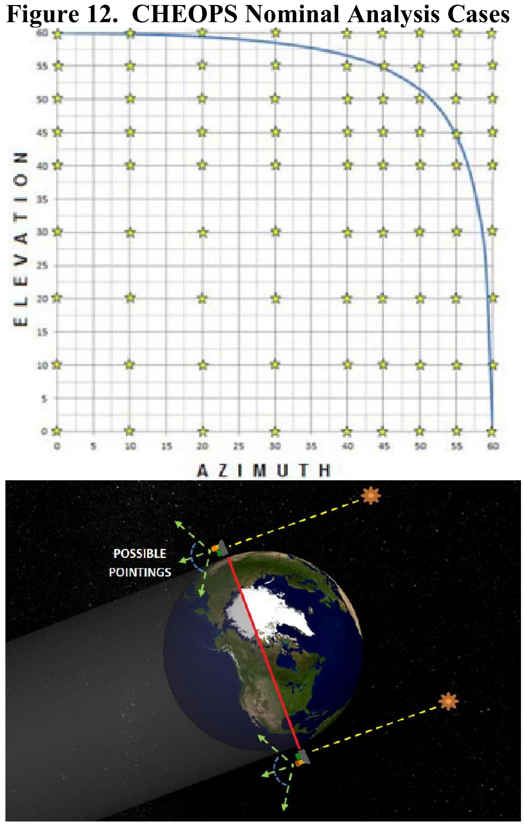


The following uncertainty margin (UM) policy has been applied:

- In general, for platform units controlled via surrounding environment, UM is +/- 8ºC (corresponding to CDR status and based on AS250 heritage).
- For the battery, which incorporates internal heating lines keeping the unit always controlled, UM is +/- 3ºC (also based on AS250 heritage).
- For other units actively controlled via heating lines, but not incorporated within the unit design (OBC and STR-OH), UM is +8 / -3ºC (also based on AS250 heritage).
- For Propulsion Module units, UM is +/- 5ºC, as per PM22 test correlation results.

Analysis cases have been selected to cover the worst envelope of hot and cold cases in both nominal operation and safe mode. Orbits in different epochs of the year and for different observation targets, as explained below, have been analysed. Safe mode and Launch cases have also been analysed in order to verify the performances in terms of heater power consumption both for the platform and the instrument.

Figure 12. CHEOPS Nominal Analysis Cases



A. Nominal mode

Hot cases: Most of them are in Winter Solstice, as it is the epoch of the year when the solar constant is maximum (1428 W/m2), and CHEOPS orbit is subjected to the largest possible Sun illuminated terrestrial area in the year. EOL thermo-optical properties have been considered. Different cases have been analysed regarding the envelope of target stars to be observed by the telescope.

February 4th has also been analysed, as it is the day of the year with a higher solar constant but no eclipse. This date is relevant to the units located on –X side of the platform and therefore influenced by the coupling with the solar array via mounting brackets.

Cold cases: All of them correspond to a target star within 0º elevation and 0º azimuth, as the sun is perpendicular to the central solar array, which is shadowing the rest of the SC. BOL thermo-optical properties have been considered. The operating cold worst case occurs on April 10th , for the baseline orbit of 650 km 6:00 AM, as CHEOPS orbit is aligned with the dusk/dawn line and only a negligible portion of albedo and sun heat load are reflected on the Instrument by the BCA cover. Different epochs of the year have also been analysed (eclipses, minimum solar constant…) as a sensitivity study.

Table 4. CHEOPS Thermal Analysis Results Nominal BOL (Temperatures in ºC). *Maximum heating lines average power consumption is 36.1W (15W for the platform lines and 21.1W for the instrument lines)*

EQUIPMENT	Min Calc	Max Calc	Min Pred	Max Pred	Min Design	Max Design	Margin Min	Margin Max	Excursion
BATTERY	21,1	25,6	18,1	28,6	10,0	30,0	8,1	1,4	4,5
BEE	16,3	27,6	8,3	35,6	-20,0	50,0	28,3	14,4	11,3
MAG+Z	2,7	6,7	-5,3	14,7	-15,0	45,0	9,7	30,3	4,0
MAG-Z	3,1	7,2	-4,9	15,2	-15,0	45,0	10,1	29,8	4,2
MGT_X	12,1	15,8	4,1	23,8	-25,0	60,0	29,1	36,2	3,7
MGT_Y	13,4	17,0	5,4	25,0	-25,0	60,0	30,4	35,0	3,6
MGT_Z	11,0	15,2	3,0	23,2	-25,0	60,0	28,0	36,8	4,2
OBC	22,0	23,1	14,0	31,1	-20,0	50,0	34,0	18,9	1,1
PCDU	12,9	21,7	4,9	29,7	-20,0	50,0	24,9	20,3	8,7
RIU	7,4	19,5	-0,6	27,5	-20,0	50,0	19,4	22,5	12,1
RW+Y+Z	21,1	26,3	13,1	34,3	-20,0	60,0	33,1	25,7	5,2
RW+Y-Z	20,9	26,4	12,9	34,4	-20,0	60,0	32,9	25,6	5,5
RW-Y+Z	18,4	23,0	10,4	31,0	-20,0	60,0	30,4	29,0	4,6
RW-Y-Z	19,1	23,7	11,1	31,7	-20,0	60,0	31,1	28,3	4,6
SBT+Z	9,2	21,5	1,2	29,5	-20,0	50,0	21,2	20,5	12,3
SBT-Z	8,5	11,7	0,5	19,7	-20,0	50,0	20,5	30,3	3,2
SEM	17,4	22,9	9,4	30,9	-20,0	35,0	29,4	4,1	5,5
STRE+Y	15,4	20,8	7,4	28,8	-20,0	55,0	27,4	26,2	5,4
STRE-Y	11,8	18,2	3,8	26,2	-20,0	55,0	23,8	28,8	6,4

EQUIPMENT	Min Calc	Max Calc	Min Pred	Max Pred	Min Design	Max Design	Margin Min	Margin Max	Excursion
S-BAND_ANTENNAS:+Z-Y	-19,1	-3,0	-27,1	5,0	-100,0	95,0	72,9	90,0	16,1
S-BAND_ANTENNAS:+Z+Y	-17,0	1,5	-25,0	9,5	-100,0	95,0	75,0	85,5	18,5
S-BAND_ANTENNAS:-Z-Y	0,0	8,2	-8,0	16,2	-100,0	95,0	92,0	78,8	8,3
S-BAND_ANTENNAS:-Z+Y	-2,4	5,2	-10,4	13,2	-100,0	95,0	89,6	81,8	7,6
STR_OH:SIDE-Y:OH	-9,1	-7,9	-17,1	0,1	-25,0	60,0	7,9	59,9	1,2
STR_OH:SIDE+Y:OH	-9,1	-8,0	-17,1	0,0	-25,0	60,0	7,9	60,0	1,1
BCA_COLLAR:PANEL	-30,0	-4,1	-40,0	5,9	-100,0	100,0	60,0	94,1	25,9
RING	-1,6	39,5	-11,6	49,5	-100,0	100,0	88,4	50,5	41,0
SOLAR_ARRAY:CENTRAL:CELLS	-27,6	122,1	-37,6	132,1	-130,0	155,0	92,4	22,9	149,6
SOLAR_ARRAY:LATERAL+Y:CELLS	-50,9	39,7	-60,9	49,7	-130,0	155,0	69,1	105,3	90,6
SOLAR_ARRAY:LATERAL-Y:CELLS	-51,4	39,2	-61,4	49,2	-130,0	155,0	68,6	105,8	90,6
BCA_SRP	-27,8	-13,2	-37,8	-3,2	-65,0	50,0	27,2	53,2	14,6
OTA_SRP	9,2	14,2	-0,8	24,2	-20,0	50,0	19,2	25,8	5,0

Table 5. CHEOPS Thermal Analysis Results Nominal EOL (Temperatures in ºC). *Maximum heating lines average power consumption is 33.1W (15.6W for the platform lines and 17.5W for the instrument lines*

EQUIPMENT	Min Calc	Max Calc	Min Pred	Max Pred	Min Design	Max Design	Margin Min	Margin Max	Excursion
BATTERY	20,0	27,2	17,0	30,2	10,0	30,0	7,0	-0,2	7,3
BEE	16,8	29,0	8,8	37,0	-20,0	50,0	28,8	13,0	12,3
MAG+Z	4,2	13,8	-3,8	21,8	-15,0	45,0	11,2	23,2	9,6
MAG-Z	4,5	14,2	-3,5	22,2	-15,0	45,0	11,5	22,8	9,7
MGT_X	14,0	18,0	6,0	26,0	-25,0	60,0	31,0	34,0	4,1
MGT_Y	15,2	19,0	7,2	27,0	-25,0	60,0	32,2	33,0	3,8
MGT_Z	12,9	17,5	4,9	25,5	-25,0	60,0	29,9	34,5	4,6
OBC	22,0	24,4	14,0	32,4	-20,0	50,0	34,0	17,6	2,4
PCDU	14,3	26,5	6,3	34,5	-20,0	50,0	26,3	15,5	12,2
RIU	9,2	23,8	1,2	31,8	-20,0	50,0	21,2	18,2	14,6
RW+Y+Z	21,2	27,7	13,2	35,7	-20,0	60,0	33,2	24,4	6,4
RW+Y-Z	20,9	27,8	12,9	35,8	-20,0	60,0	32,9	24,2	6,9
RW-Y+Z	20,3	24,6	12,3	32,6	-20,0	60,0	32,3	27,4	4,3
RW-Y-Z	21,0	25,1	13,0	33,1	-20,0	60,0	33,0	26,9	4,1
SBT+Z	11,7	26,7	3,7	34,7	-20,0	50,0	23,7	15,3	15,0
SBT-Z	10,1	19,0	2,1	27,0	-20,0	50,0	22,1	23,0	8,9
SEM	18,1	24,2	10,1	32,2	-20,0	35,0	30,1	2,8	6,1
STRE+Y	17,2	23,0	9,2	31,0	-20,0	55,0	29,2	24,0	5,8
STRE-Y	12,7	20,5	4,7	28,5	-20,0	55,0	24,7	26,5	7,8

EQUIPMENT	Min Calc	Max Calc	Min Pred	Max Pred	Min Design	Max Design	Margin Min	Margin Max	Excursion
S-BAND_ANTENNAS:+Z-Y	-22,3	9,6	-30,3	17,6	-100,0	95,0	69,7	77,4	31,9
S-BAND_ANTENNAS:+Z+Y	-22,6	11,4	-30,6	19,4	-100,0	95,0	69,4	75,6	34,0
S-BAND_ANTENNAS:-Z-Y	1,6	23,1	-6,4	31,1	-100,0	95,0	93,6	63,9	21,5
S-BAND_ANTENNAS:-Z+Y	-0,6	23,4	-8,6	31,4	-100,0	95,0	91,4	63,6	24,0
STR_OH:SIDE-Y:OH	-9,1	20,1	-17,1	28,1	-25,0	60,0	7,9	31,9	29,2
STR_OH:SIDE+Y:OH	-9,1	28,8	-17,1	36,8	-25,0	60,0	7,9	23,2	37,9
BCA_COLLAR:PANEL	-29,3	21,2	-39,3	31,2	-100,0	100,0	60,7	68,8	50,5
RING	0,1	42,4	-9,9	52,4	-100,0	100,0	90,1	47,6	42,4
SOLAR_ARRAY:CENTRAL:CELLS	-48,5	122,1	-58,5	132,1	-130,0	155,0	71,5	22,9	170,5
SOLAR_ARRAY:LATERAL+Y:CELLS	-73,1	119,1	-83,1	129,1	-130,0	155,0	46,9	25,9	192,2
SOLAR_ARRAY:LATERAL-Y:CELLS	-83,6	118,4	-93,6	128,4	-130,0	155,0	36,4	26,6	202,0
BCA_SRP	-27,1	5,9	-37,1	15,9	-65,0	50,0	27,9	34,1	33,1
OTA_SRP	11,0	18,6	1,0	28,6	-20,0	50,0	21,0	21,4	7,6

Results presented in Table 4 and Table 5 correspond to extreme temperatures within a stabilized orbit for the complete envelope of nominal analysis cases. Margins with respect to design limits are quite comfortable for all the equipment, except for the battery, which is slightly negative, due to it's very narrow operating temperature range. It has to be noted that maximum temperatures in the battery occur when the sun is illuminating the central solar panel in the worst conditions (since the battery is installed in the panel behind it) and, therefore, not discharging. Furthermore, the battery supplier allows for temperature excursions up to 35ºC for limited periods of time without detriment of performances.

B. Safe mode

Safe Mode units dissipations have been taken into account (Instrument OFF). In stabilized Safe Mode the SC stays with the solar array perpendicular to Sun and a roll rate around telescope axis of 2 rev/orbit (0,00214 rad/s). This is a cold sizing case for the platform and the instrument survival heaters. BOL properties have been analysed.

During transitions from Nominal to Safe stabilized mode, it may happen to have direct solar flux on platform radiators. According to AOCS analysis, the maximum time of continuous sun illumination in the radiator panels is 20 minutes (1200 sec). Several thermal analyses have been carried out to prove that maximum design temperature of the platform equipment is not exceeded during the entrance to safe mode. The worst conservative hot analysis case for the platform thermal control is to be one whole orbit (w/o eclipse) with the radiators (+X, +X-Y or +X+Y panels) pointing to the Sun. EOL conditions and Safe Mode units dissipation (Instrument OFF) have been considered. Temperatures from nominal mode analyses have been set as initial temperatures for these cases.

Table 6. CHEOPS Thermal Analysis Results Safe Mode (Temperatures in ºC). *Maximum heating lines average power consumption is 33.3W (31.3W for the platform lines and 0W for the instrument lines)*

EQUIPMENT	Min Calc	Max Calc	Min Pred	Max Pred	Min Design	Max Design	Margin Min	Margin Max	Excursion
BATTERY	19,4	21,0	16,4	24,0	15,0	30,0	1,4	6,0	1,6
BEE	9,1	24,8	1,1	32,8	-30,0	60,0	31,1	27,2	15,8
MAG+Z	7,0	25,2	-1,0	33,2	-15,0	45,0	14,0	11,8	18,2
MAG-Z	7,6	25,7	-0,4	33,7	-15,0	45,0	14,6	11,3	18,1
MGT_X	16,7	20,9	8,7	28,9	-25,0	60,0	33,7	31,1	4,2
MGT_Y	17,9	20,6	9,9	28,6	-25,0	60,0	34,9	31,4	2,7
MGT_Z	15,3	18,9	7,3	26,9	-25,0	60,0	32,3	33,1	3,5
OBC	10,3	27,5	2,3	35,5	-20,0	50,0	22,3	14,5	17,2
PCDU	9,9	28,3	1,9	36,3	-20,0	50,0	21,9	13,7	18,4
RIU	4,2	28,0	-3,8	36,0	-20,0	50,0	16,2	14,0	23,8
RW+Y+Z	17,0	23,5	9,0	31,5	-20,0	60,0	29,0	28,5	6,5
RW+Y-Z	17,2	23,3	9,2	31,3	-20,0	60,0	29,2	28,7	6,1
RW-Y+Z	13,3	22,3	5,3	30,3	-20,0	60,0	25,3	29,7	9,0
RW-Y-Z	14,0	22,7	6,0	30,7	-20,0	60,0	26,0	29,3	8,7
SBT+Z	4,8	27,1	-3,2	35,1	-20,0	50,0	16,8	14,9	22,4
SBT-Z	3,5	30,8	-4,5	38,8	-20,0	50,0	15,5	11,2	27,3
SEM	8,6	20,5	0,6	28,5	-30,0	60,0	30,6	31,5	11,9
STRE+Y	4,6	23,2	-3,4	31,2	-30,0	60,0	26,6	28,8	18,6
STRE-Y	7,6	20,0	-0,4	28,0	-30,0	60,0	29,6	32,0	12,3

EQUIPMENT	Min Calc	Max Calc	Min Pred	Max Pred	Min Design	Max Design	Margin Min	Margin Max	Excursion
S-BAND_ANTENNAS:+Z-Y	-12,1	5,0	-20,1	13,0	-100,0	95,0	79,9	82,0	17,1
S-BAND_ANTENNAS:+Z+Y	-8,0	8,9	-16,0	16,9	-100,0	95,0	84,0	78,1	17,0
S-BAND_ANTENNAS:-Z-Y	-2,0	32,3	-10,0	40,3	-100,0	95,0	90,0	54,7	34,3
S-BAND_ANTENNAS:-Z+Y	-5,9	27,3	-13,9	35,3	-100,0	95,0	86,1	59,7	33,2
STR_OH:SIDE-Y:OH	-19,2	6,4	-27,2	14,4	-30,0	60,0	2,8	45,6	25,5
STR_OH:SIDE+Y:OH	-19,2	31,6	-27,2	39,6	-30,0	60,0	2,8	20,4	50,8
BCA_COLLAR:PANEL	-33,3	26,9	-43,3	36,9	-100,0	100,0	56,7	63,1	60,2
RING	-3,6	39,8	-13,6	49,8	-100,0	100,0	86,4	50,2	43,4
SOLAR_ARRAY:CENTRAL:CELLS	-55,0	117,5	-65,0	127,5	-130,0	155,0	65,0	27,5	172,5
SOLAR_ARRAY:LATERAL+Y:CELLS	-47,1	118,1	-57,1	128,1	-130,0	155,0	72,9	26,9	165,2
SOLAR_ARRAY:LATERAL-Y:CELLS	-57,1	109,8	-67,1	119,8	-130,0	155,0	62,9	35,2	166,9
BCA_SRP	-31,2	12,3	-41,2	22,3	-80,0	60,0	38,8	37,7	43,5
OTA_SRP	4,4	22,0	-5,6	32,0	-30,0	60,0	24,4	28,0	17,6

Results presented in Table 6 correspond to extreme temperatures for the complete envelope of safe mode analysis cases, including both the stabilized phase and the safe mode entrance transient phases. Margins with respect to design limits are quite comfortable for all the equipment. Minimum margins appear in the units controlled by heaters: battery and star tracker optical heads.

C. Launch

Launch units dissipations have been taken into account (Instrument OFF). After separation, the S/C can stay up to 4 hours 15 minutes having incident external fluxes on any direction.

Different directions of solar incidence have been analysed, to verify the SC performances in terms of temperatures and heater power consumption, as detailed in next table. Aerothermal fluxes in the first 20 seconds have also been applied.

Thermo-optical properties are corresponding to BOL and initial temperature is defined at 10ºC.

Table 7. CHEOPS Thermal Analysis Results Launch (Temperatures in ºC). *Maximum heating lines average power consumption is 13.5W (13.5W for the platform lines and 0W for the instrument lines)*

EQUIPMENT	Min Calc	Max Calc	Min Pred	Max Pred	Min Design	Max Design	Margin Min	Margin Max	Excursion
BATTERY	19,0	22,8	16,0	25,8	15,0	30,0	1,0	4,2	3,8
BEE	-6,1	11,5	-14,1	19,5	-30,0	60,0	15,9	40,5	17,6
MAG+Z	-3,8	18,1	-11,8	26,1	-15,0	45,0	3,2	18,9	21,9
MAG-Z	-3,9	18,0	-11,9	26,0	-15,0	45,0	3,1	19,0	21,9
MGT_X	-3,3	17,9	-11,3	25,9	-25,0	60,0	13,7	34,1	21,3
MGT_Y	-1,1	14,7	-9,1	22,7	-25,0	60,0	15,9	37,3	15,8
MGT_Z	-3,2	14,4	-11,2	22,4	-25,0	60,0	13,8	37,6	17,6
OBC	7,9	28,3	-0,1	36,3	-20,0	50,0	19,9	13,7	20,4
PCDU	2,2	24,8	-5,8	32,8	-20,0	50,0	14,2	17,2	22,6
RIU	0,9	28,9	-7,1	36,9	-20,0	50,0	12,9	13,1	28,0
RW+Y+Z	-3,1	12,9	-11,1	20,9	-20,0	60,0	8,9	39,1	16,0
RW+Y-Z	-2,0	13,1	-10,0	21,1	-20,0	60,0	10,0	38,9	15,1
RW-Y+Z	-4,3	13,5	-12,3	21,5	-20,0	60,0	7,7	38,5	17,8
RW-Y-Z	-3,5	13,6	-11,5	21,6	-20,0	60,0	8,5	38,4	17,1
SBT+Z	-5,2	24,2	-13,2	32,2	-20,0	50,0	6,8	17,8	29,4
SBT-Z	-1,7	24,8	-9,7	32,8	-20,0	50,0	10,3	17,2	26,5
SEM	-7,5	12,6	-15,5	20,6	-30,0	60,0	14,5	39,4	20,2
STRE+Y	-8,8	17,5	-16,8	25,5	-30,0	60,0	13,2	34,5	26,2
STRE-Y	-3,3	16,5	-11,3	24,5	-30,0	60,0	18,7	35,5	19,9

EQUIPMENT	Min Calc	Max Calc	Min Pred	Max Pred	Min Design	Max Design	Margin Min	Margin Max	Excursion
S-BAND_ANTENNAS:+Z-Y	-51,8	10,0	-59,8	18,0	-100,0	95,0	40,2	77,0	61,8
S-BAND_ANTENNAS:+Z+Y	-50,9	10,0	-58,9	18,0	-100,0	95,0	41,1	77,0	60,9
S-BAND_ANTENNAS:-Z-Y	-2,9	26,2	-10,9	34,2	-100,0	95,0	89,1	60,8	29,1
S-BAND_ANTENNAS:-Z+Y	-4,6	23,2	-12,6	31,2	-100,0	95,0	87,4	63,8	27,8
STR_OH:SIDE-Y:OH	-19,1	48,1	-27,1	56,1	-30,0	60,0	2,9	3,9	67,2
STR_OH:SIDE+Y:OH	-19,2	51,5	-27,2	59,5	-30,0	60,0	2,8	0,5	70,7
BCA_COLLAR:PANEL	-22,8	48,0	-32,8	58,0	-100,0	100,0	67,2	42,0	70,8
RING	-4,5	30,3	-14,5	40,3	-100,0	100,0	85,5	59,7	34,8
SOLAR_ARRAY:CENTRAL:CELLS	-91,0	114,8	-101,0	124,8	-130,0	155,0	29,0	30,2	205,8
SOLAR_ARRAY:LATERAL+Y:CELLS	-91,0	80,2	-101,0	90,2	-130,0	155,0	29,0	64,8	171,2
SOLAR_ARRAY:LATERAL-Y:CELLS	-90,4	80,5	-100,4	90,5	-130,0	155,0	29,6	64,5	170,9
BCA_SRP	-21,9	44,8	-31,9	54,8	-80,0	60,0	48,1	5,2	66,6
OTA_SRP	-5,1	19,5	-15,1	29,5	-30,0	60,0	14,9	30,5	24,6

Results presented in Table 7 correspond to extreme temperatures for the complete envelope of launch transient analysis cases. Margins with respect to design limits are quite comfortable for all the equipment. Minimum margins appear again in the units controlled by heaters: battery and star tracker optical heads.

V. Conclusion

CHEOPS satellite overview and thermal architecture has been presented in this paper. The chosen approach is the result of a complex activity, with which all the main criticalities have been successfully solved. The challenge for the thermal architecture, as well as for the overall spacecraft, has been to balance the requested mission performances to satisfy the scientific needs, with the design-to-cost and fast track approach. In order to accomplish this challenge, a maximum re-use of existing building blocks and design solutions has been a key parameter.

Thermal analysis reported within this paper allow to confirm that proposed thermal design is suitable for CHEOPS mission needs. Temperatures for Platform units and CIS interfaces have been calculated for the different operational and non-operational scenarios, and it has been proven that they always remain within their design limits. Thermal excursions have been calculated for Platform and CIS units for operational scenarios, showing compliance to requested stability constraints. Heat fluxes between Platform and CIS have been minimized by the sunshield and platform thermal design, in order to maintain CIS performances. The analyzed thermal control performances will be verified by thermal balance test. Indeed, the test will validate the Platform TMM and the thermal interfaces to the CIS.

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VII. References

None.