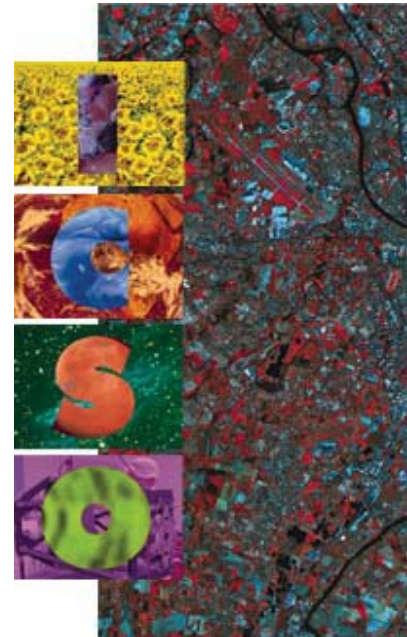


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The IASI cold box subsystem (CBS) a passive cryocooler for cryogenic detectors and optics

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**THE IASI COLD BOX SUBSYSTEM (CBS)
A PASSIVE CRYOCOOLER FOR CRYOGENIC DETECTORS & OPTICS**

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RESUME – Dans l’espace, refroidir des détecteurs Infra Rouge et leurs optiques à des températures cryogéniques soulève toujours la même question : quel est le meilleur moyen pour assurer simultanément le refroidissement, la stabilité thermique, le découplage mécanique ainsi qu’un positionnement précis des composants du plan focal, le tout en une solution compacte et légère ? Le refroidisseur cryogénique passif développé par Alcatel SPace Industries sous contrat CNES pour le programme IASI (Infrared Atmospheric Sounding Interferometer), apporte une solution performante pour des niveaux de température de 90K à 100K. Nous vous proposons de découvrir l’architecture et le plan de validation des performances de la CBS.

ABSTRACT – In space, cooling down Infra Red detectors and optics to cryogenic temperature raises always the same issue : what is the best way to manage simultaneously thermal cooling, stability, mechanical decoupling and accurate focal plane components location, in a lightweight and compact solution ? The passive cryocooler developed by Alcatel SPace Industries under CNES contract in the frame of the IASI instrument (Infrared Atmospheric Sounding Interferometer), offers an efficient solution for 90K to 100K temperature levels. We intend you to present the architecture and performance validation plan of the CBS.

1- INTRODUCTION

Since years, the Earth Observation needs even higher performance detection systems. For Infra Red domain, current quantic detectors require to cool down the detectors and optics of the focal plane to cryogenic temperature (90 K to 100K), in order to limit as lowest as possible parasitic light and temperature effects that would saturate detectors, making them non-operational. The challenge consists in managing simultaneously thermal cooling and stability as well as mechanical decoupling and accurate focal plane components location.

In the frame of the IASI instrument (Infrared Atmospheric Sounding Interferometer), issued from a collaboration between French space agency (CNES) and EUMETSAT, Alcatel SPace Industries (ASPI) develops a very efficient passive cryocooler, under CNES contract. This cryocooler will be tested on ground and delivered until end of 2001. It is designed to cool down the IASI Infra Red cryogenic detectors and optics below 100 K. The selected concept guarantees high thermal stability and very accurate location of the focal plane components, one of the permanent design drivers being the thermoelastic constraints induced by cryogenic temperature. So, the CBS design is supported by detailed thermal and mechanical modelings, as well as technological tests, and will be validated through global CBS performance tests.

2- MAIN REQUIREMENTS

The CBS is part of the IASI instrument, as presented in figure-1. It takes on board the IASI cryogenic Infra Red detectors (3 to 15 μ m band) and their dedicated cryogenic optics. It appears that the IASI detection chain performance highly depends on the CBS detectors efficiency. This is closely linked to the ratio between the optical useful flux reaching the detectors microlenses and the thermal noise on the detectors. The CBS shall then maximise the useful flux via high accuracy optical pointing and stability. This is achieved by mechanical stiffness and decoupling, precise machining and finishing, limitation and anticipation

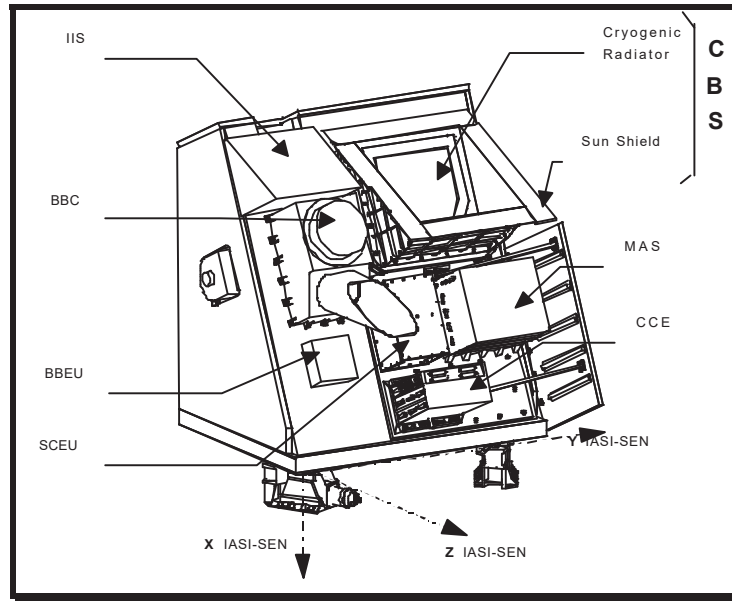


Figure-1 : CBS is part of the IASI instrument

of the thermoelastic distortions due to cooling down. Furthermore, a very efficient thermal control is necessary to optimise the radiometric performance, by decreasing the detectors proper temperature below 100K and reducing the detectors neighbouring environment temperature in order to limit as lowest as possible the parasitic fluxes. The CBS general layout is exposed in figure-2.

Therefore the CBS architecture is a compromise between thermal decoupling and stability, as well as mechanical stiffness, decoupling and stability. These thermal and mechanical often conflicting requirements are fully overlapped within the following strong constraints :

- a reduced allocated volume that induces not only lots of architectural constraints but also the challenge to decrease the focal plane temperature from 300 K to 90 K on a very short distance (200 mm) purely passively (active cryogenic device size being too important) ;

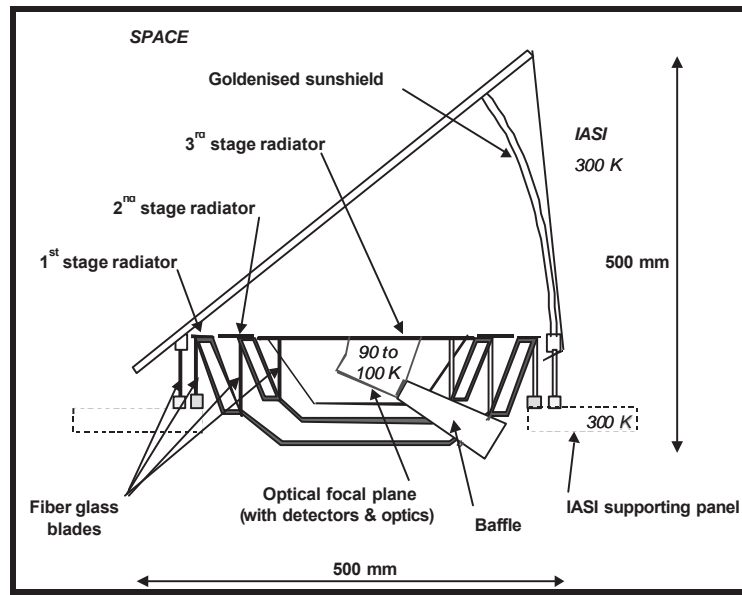


Figure-2 : decoupling & stability in a compact layout

- a reduced allocated mass budget that leads to lightweight the structural parts, this being in contradiction with the high stability needed for such an application ;
- the requested possibility of decontamination heating up to 300K of the cryogenic focal plane (power cables joining the IASI ambient environment to the CBS coldest part are then compulsory), that is paradoxical w.r.t. the very strong thermal decoupling need.

The CBS design has then to fulfill the required beginning of life performances synthesized in table-1 and the stability presented in table-2 hereafter.

An important request concerns the level of contamination on the optics and detectors. Indeed, molecular and particular contamination could reduce the useful optical flux on the detectors, decreasing the detection performances. The CBS manufacturing and AIT activities shall then be compatible of the severe contamination levels requested at IASI delivery (molecular < 500ppm & particular < 10⁻⁷g/cm²). Besides this, an in orbit CBS decontamination heating system shall be implemented, as well as the possibility of heating during early orbit phases.

CBS global pointing	Range 250µm 1000µrad
Optics positioning	Range 40µm 800µrad
Operational detectors temperature	Within 85K & 99K Regulation with 1K of accuracy
Survival temperature	Within 80K & 333K
Mass	< 23 kg (including detectors, optics & sunshield)
Stiffness	First frequency > 110Hz
Mechanical environment	Quasi static loads : 45g

Table-1 : CBS requirements in BOL (Beginning of Life) constitute a real challenge

Lifetime	5 years in orbit+ 8 years under ground AIT & storage
CBS global pointing short term stability	Range 10µm
CBS global pointing long term stability	Range 150µm 300µrad
Operational detectors temperature stability	< +/-0.1K on 80s < +/-0.3K per orbit

Table-2 : stability requirements are a basis of CBS design

3- CBS OPTICAL ARCHITECTURE

The CBS aims to collect the optical signal coming from the interferometer, to split it into three spectral bands and to convert it into electrical signal delivered to IASI instrument treatment electronic (see figure-3).

The transformation of the final optical signal into the electrical one is the task of the CAU (detectors). The COU (lenses & dichroics) collect, split and focus the optical flux. CAU and COU are mounted into the CBS cryogenic focale plane (3rd stage optical box), as presented in figure-4.

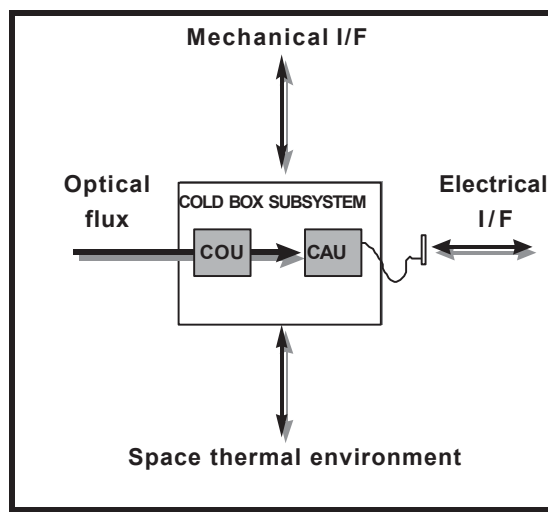


Figure-3 : The CBS is the eyes of IASI

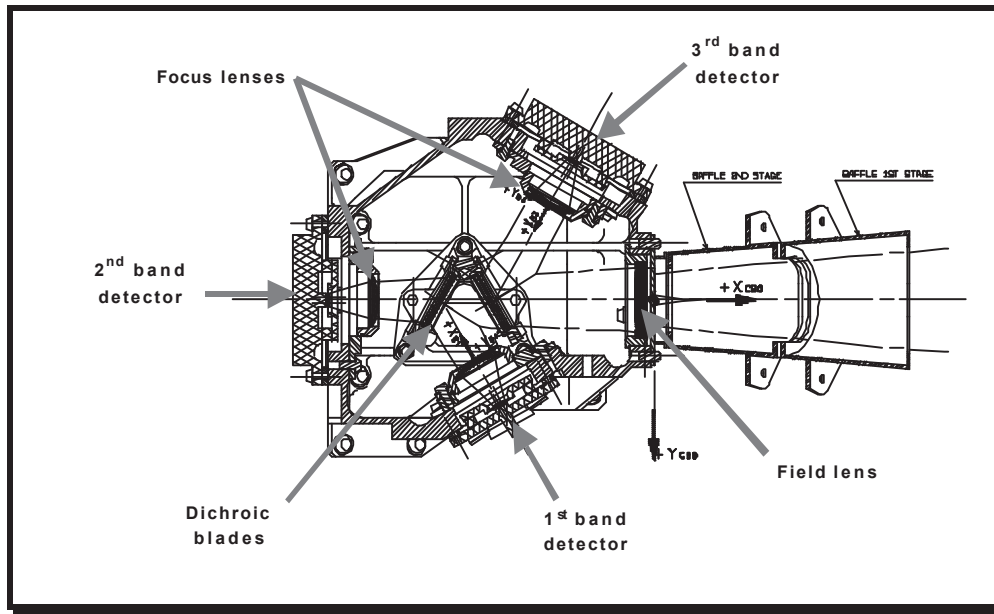


Figure-4 : the CBS optical box houses optics & detectors

4- CBS THERMAL ARCHITECTURE

The CBS being a purely passive cryogenic radiator, its thermal efficiency depends mainly on the three following parameters :

- ↳ a very efficient thermal insulation from the inner fluxes coming from IASI cavities via :
- a three stages architecture to filter as well as possible IASI fluxes ;

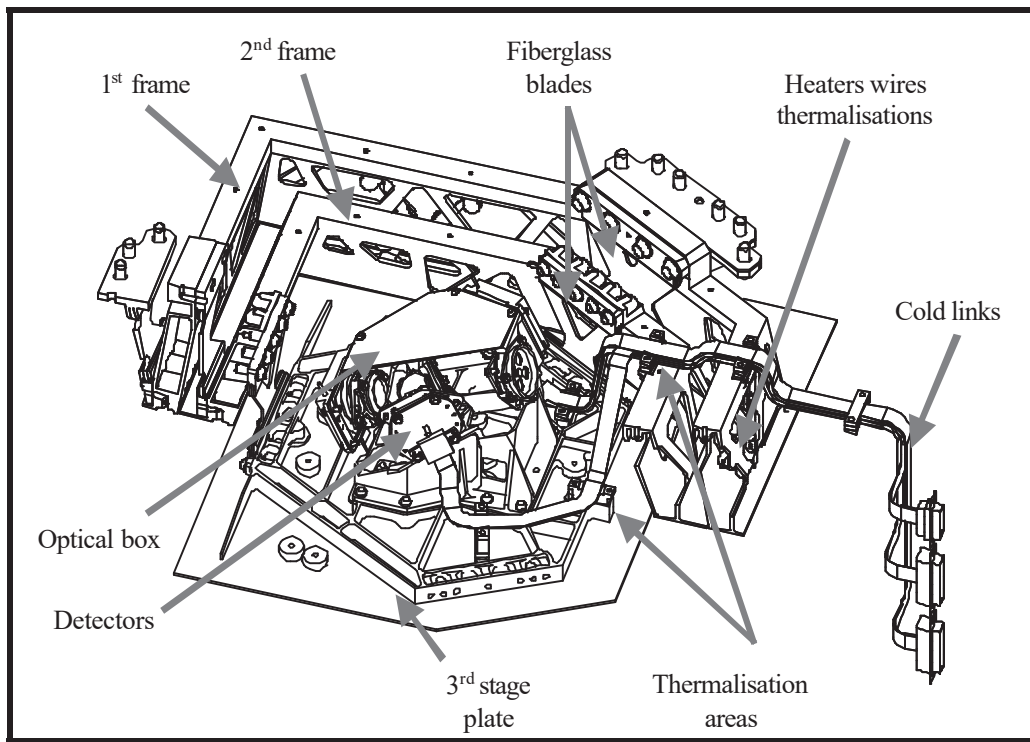


Figure-5 : the CBS 3 stages assembly equipped with detectors, cold links & optics

- high efficiency MLI (Multi Layer Insulation composed of 3 superposed sets of 7 layers MLI with spacers and an external double goldenised kapton), laid on every stage external side, this solution being very efficient to reduce thermal leaks due to singularities ;
- a radiative protection by a very low emittance double goldenised SLI (Single Layer Insulation) for structures not covered by MLI ;
- fibreglass + cyanate “ester” resin discoupling blades with optimised shapes (w.r.t. thermo mechanical compromise) ;

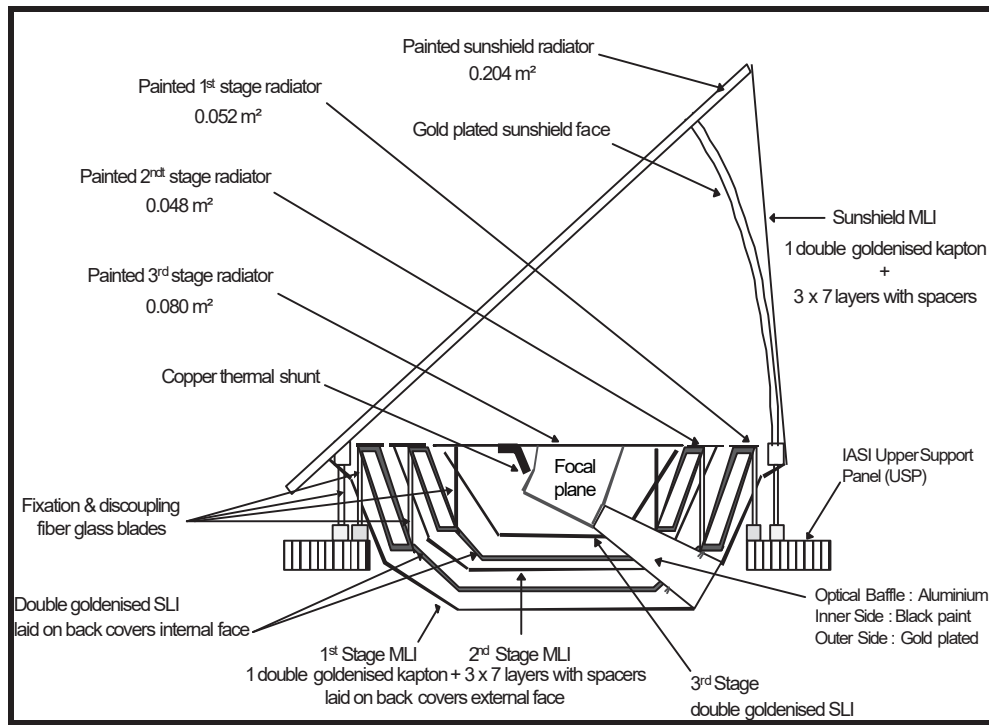


Figure-6 : discoupling & high rejection capability are the drivers of the thermal concept

- an extremely reduced incoming power via detectors cold links, by optimisation of their design and use of thermalisation clamps on each stage ;
- a reduced incoming power via the active thermal control wires, by using low section cables made of low thermal conductive materials and a very efficient thermalisation technique.

↪ a maximum limitation of the external Earth, sun and albedo fluxes on the radiator by :

- location and orientation of the CBS radiators plane with maximum field of view towards space, and minimum Earth and albedo view factor (radiator plane in the Earth limb direction during operational phases) ;

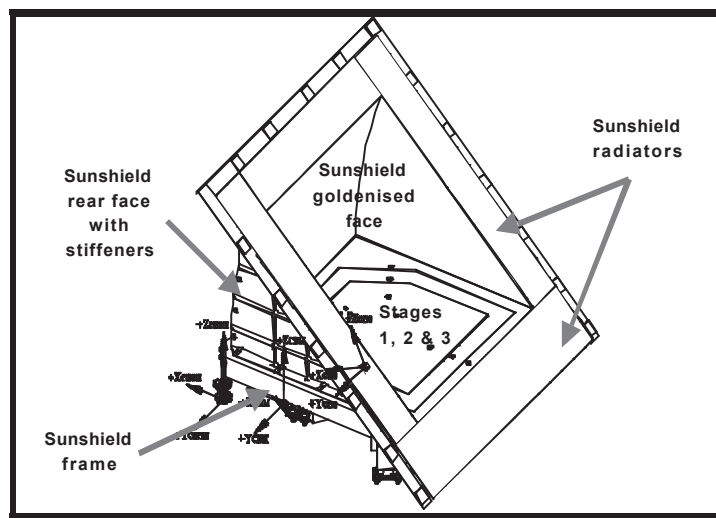


Figure-7 : a sunshield to protect the 3 CBS stages

- protection of the CBS radiators from sun illumination during operationnal pointing, by a specular and low emissive gold plated sunshield, with high polishing quality ($R_a < 3 \text{ nm}$) ;
 - protection of the sunshield gold plated face by a dielectric layer, cleanable in case of pollution occurring during CBS ground lifetime.
- ↪ the 3 stages and sunshield radiators are covered by PCBE white paint, presenting high emittance at 90 K and low solar absorbtance for temperature limitation during non operational solar illumination.

The thermal regulation of the focal plane (detectors and optics) is completed by :

- ↪ thermal copper shunts to reduce the temperature differential between radiator and focal plane ;
- ↪ a cryogenic PI (Proportional Integral) automatic regulation system, to guarantee mid and long term stability of detectors temperature.

5- CBS MECHANICAL ARCHITECTURE

The CBS mechanical design, in terms of materials, manufacturing and inter-stages filtering fixation solution, is driven by the following main requirements :

- ↪ severe alignment and stability required on optics and detectors of the 3rd stage focal plane at cryogenic temperature, that oriented the following design solutions :
 - the use of Titanium for 3rd stage structure to limit differential thermoelastic distortions when cooling down to 90 K, between CBS structure, detectors and optics (coefficient of thermal expansion of detectors housing and optics barrels homogeneous to Titanium one) ;
 - a special attention paid on the optical box machining, in order to ensure a very precise location of optics and detectors ;
 - the use of Titanium for 1st and 2nd stages structural frames in order to limit thermoelastic distortions when cooling down, for pointing and stability performances ;

Note : the use of Titanium for the stages avoid any sliding effects at fibreglass fixation interfaces.

↪ mass saving / stiffness compromise :

- 1st and 2nd stages Titanium frames are lightweighted structures, manufactured with investment (lost wax) casting technique, before final precise machining for global pointing need ;
- 3rd stage radiator is machined into a Titanium blank to obtain a 2mm thick radiative plate

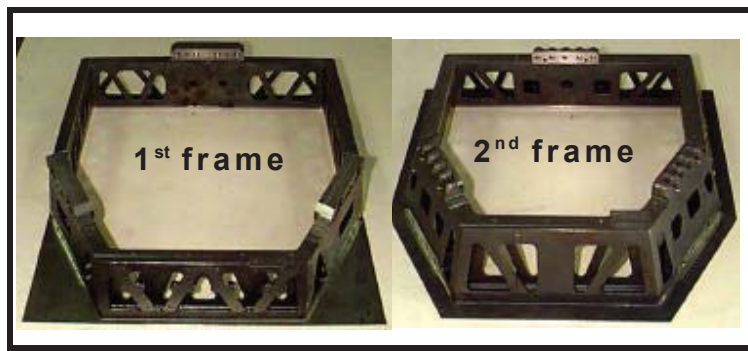


Figure-8 : 1st & 2nd lightweighted but highly stable frames

reinforced by stiffeners (figure-9 presents the 3rd stage plate once machined);

- 3rd stage monolithic optical box is precisely machined into a Titanium blank to guarantee high stability at low temperature (no internal stress release), and highly lightweighted by electroerosion technique (see figure-10).

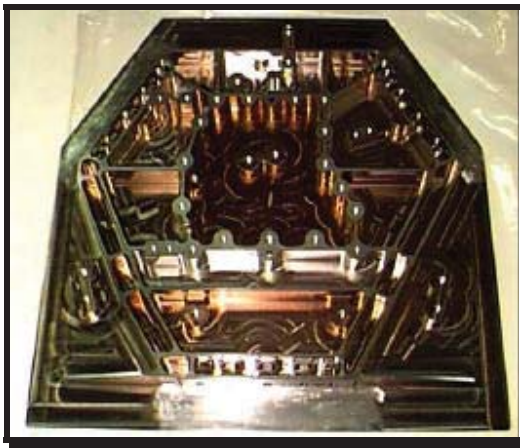


Figure-9 :
a stiffened radiative plate

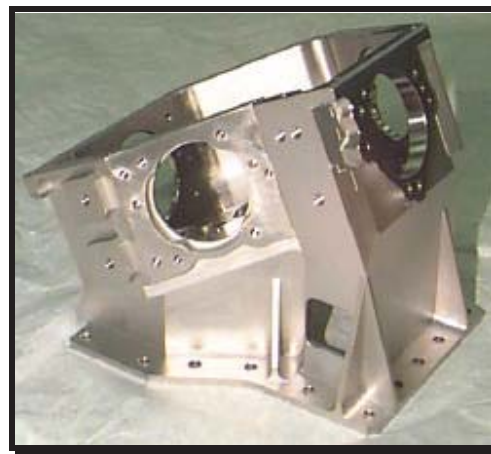
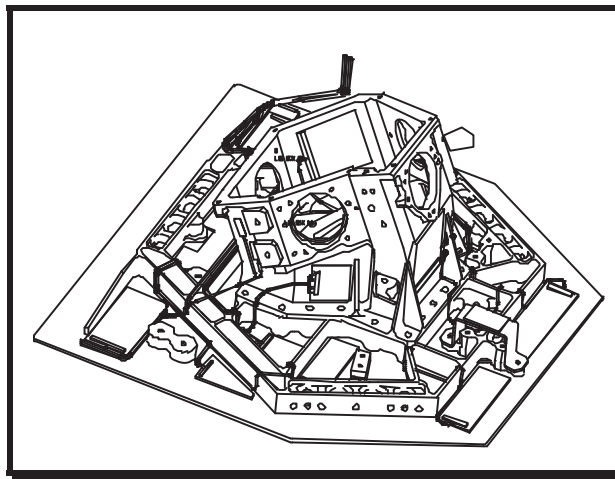


Figure-10 :
an optical box precisely machined

Figure-11 :
the 3rd stage
assembly
constitutes
the heart
of the CBS



↪ mechanical and thermal decoupling but with sufficient strength and stiffness :

➤ all the mechanical fixations (CBS / IASI interfaces, inter-stages assembly and sunshield) are realised via fibreglass + cyanate resin decoupling blades with optimised shapes (w.r.t. thermo mechanical compromise) ;

➤ fibreglass blades are bonded into Titanium end fittings. Therefore, the fibreglass wrapping is optimised to satisfy :

- compatibility with the end fittings in term of thermoelastic distortions at low temperature (differential of CTE as low as possible)

- stiffness and strength high enough to

withstand the mechanical loads mainly encountered during launch phases and to provide an accurate inter stages positioning and stability in operational mode

- minimum thermal conductivity (via optimised blade shape).

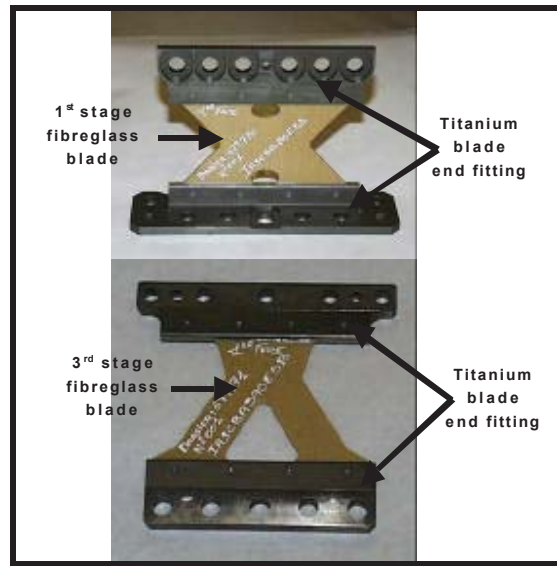


Figure-12 : decoupling blades play a major role in the thermo-mechanical behaviour

The sunshield design is a compromise between mass saving and thermoelastic stability. It is composed of :

- ↳ 3 gold plated aluminium panels, directly machined into an aluminium blank to obtain 2 mm thick shields reinforced by stiffeners, limiting active surface distortion at cold temperature. The sunshield radiators are also directly integrated in the panels (monolithic parts). This approach guarantees mass saving as well as high thermal behaviour of the sunshield.
- ↳ a lightweighted aluminium frame on which are screwed the three previous sunshield panels. This frame is also supporting an extra thermal radiator. It is then fixed on the IASI supporting panel via 4 fibreglass blades with optimised shapes (w.r.t. thermo mechanical compromise).

6- CBS MAIN PERFORMANCES

The detailed analyses and associated technological tests results are compliant with the requested performance.

Optics alignment is better than $40\mu\text{m}$ (for the most sever ones), all contributors included (manufacturing, integration, cooling down, gradients, launch residual, gravity and ageing).

One of the main challenge is related to the 3rd stage operational temperature, which is on the way of being successfully realised. The typical computed BOL temperature of the cryogenic detectors and optics is 92 K, in maximum hot environmental and orbital case. This temperature level leads to the flux balance exposed in table-3 and the following temperature spreading (see figure-13).

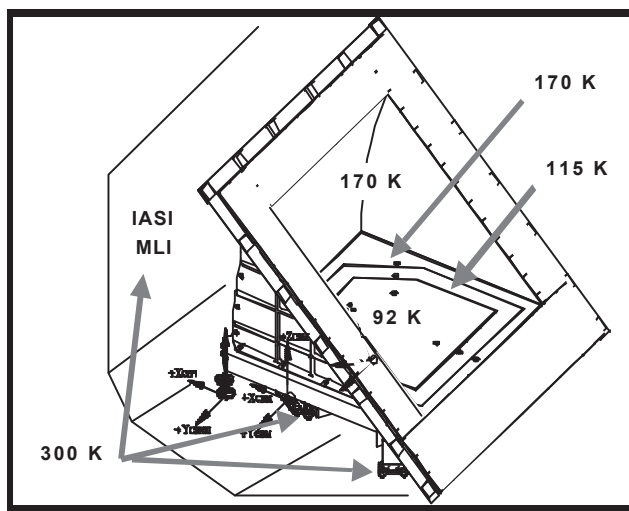


Figure-13 : 92 K on focal plane represents 200 K of decrease on 200 mm

Element	Global load
Sunshield	5950 mW (Ext. 63%, int. 37%)
Stage 1	1765 mW (Ext. 1%, int.99%)
Stage 2	405 mW (Ext. 6%, int. 94%)
Stage 3	170 mW (Ext. 9%, int. 50%, detectors dissipation = 41%)

Table 3 : the hot case CBS power budget illustrates thermal control efficiency

The thermal stability is better than specified. In particular, the results of a refined coupled transient analysis between detectors (internal model) and CBS, show that detectors fluctuation during observation of a typical flight scene cycle (duration around 10s) is less than 0.01 K.

The mechanical performance is also achieved. The 1st frequency (nominal value) is 130 Hz, partially correlated via sine vibration tests on a test mockup (see section 7) and the nominal mass is 21.8 kg .

The CBS performance is secured by refined analyses,using detailed thermal mathematical models (see figure-14) as well as detailed mechanical ones (see figure-15).

CBS design and analyses are based on a technological test program, successfully completed :

- ↪ fibreglass mechanical characterisation ;
- ↪ mechanical and thermal cycling tests on flight representative fibreglass blades ;
- ↪ development of active and passive thermal hardware bonding technique to withstand 90 K ;
- ↪ development of new wiring technique (low section and low thermal conductive cables).

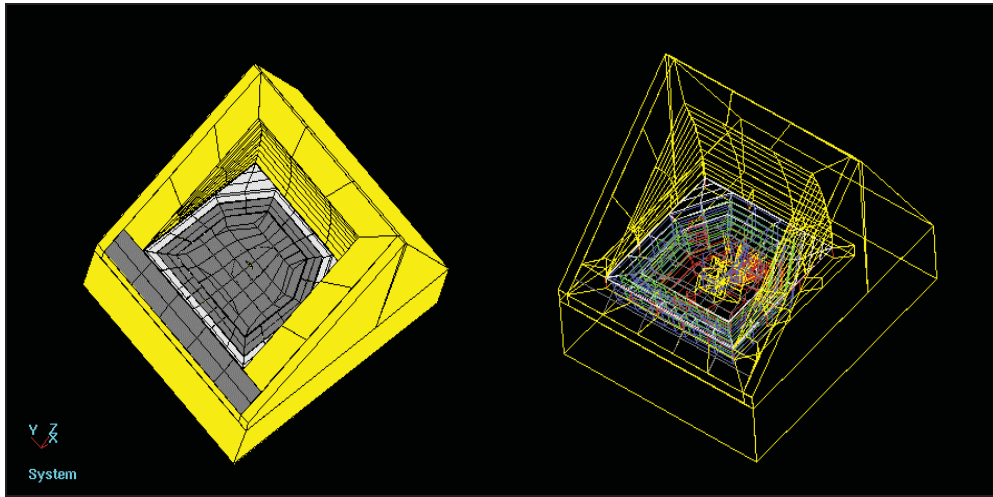


Figure-14 : highly detailed thermal models for accurate thermal predictions

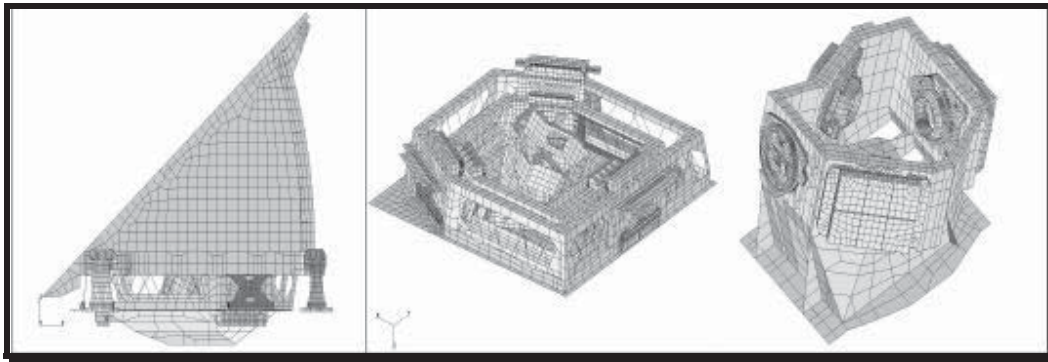


Figure-15 : highly detailed mechanical models ensure mechanical/thermoelastic behaviour

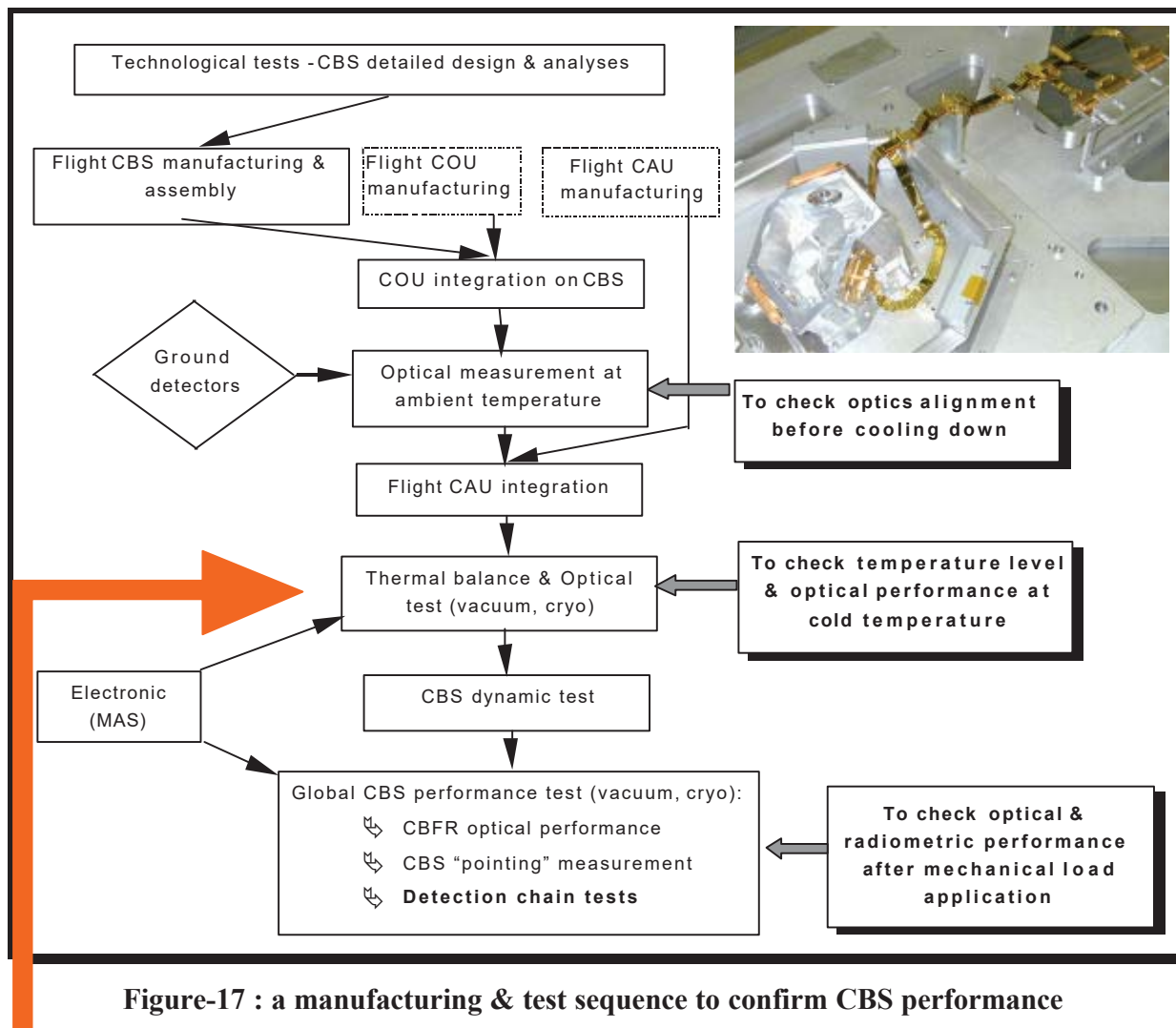
7- CBS DEVELOPMENT & VERIFICATION LOGIC

The CBS performances will be verified through a global test campaign (see figure-17) on the protoflight (PFM).

Before going to the PFM test sequence, a preliminary dynamic test has been performed with flight representative blades, in order to verify strength and stiffness (see figure-16).



Figure-16 : a successful dynamic elementary test



The first major key event will be the thermal cryo-optic test sequence to verify the temperature level and the optical performance in operational conditions. For this purpose, a specific 20 K cryogenic panel (with appropriate pyramidal active shape for high emittance need at low temperature) is developed, as well as specific optical and radiometric devices.

8- CONCLUSION

After a design phase supported by thermal and mechanical detailed analyses, associated to technological tests, the CBS PFM is now manufactured and ready for assembly phase.

This first important step enables to be confident in the CBS capability to fulfil the required performance, which will be validated in 2001 through the test sequence previously presented.

The CBS solid concept developed by ALCATEL, enhances the interest of passive cryocooler systems, thanks to the following great advantages :

- ↪ no microvibration perturbation ;
- ↪ low allocated volume ;
- ↪ high reliability ;
- ↪ no power consumption.