

Design and Test of a Concept for Solar Orbiter Heat Shield

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ABSTRACT

Solar Orbiter is the next solar-heliospheric mission in the Science Programme of ESA. The mission will provide the next major step forward in the exploration of the Sun and the heliosphere to investigate many of the fundamental problems in solar and heliospheric science. The near-Sun phase of the mission will enable the spacecraft to approach the Sun as close as 0.22 AU during part of its orbit, thereby permitting observations from a quasi helio-synchronous vantage point. During the out-of-ecliptic phase of the mission, Solar Orbiter will reach higher solar latitudes, up to 34° close to the end of the mission, to observe also the polar regions of the sun.

The 3 axis stabilized spacecraft will carry two groups of scientific instruments: In-situ instruments to study the local environment and Remote Sensing instruments to observe the sun, therefore the latter will require apertures in the face oriented towards the Sun.

One of the main design drivers for Solar Orbiter is the thermal environment, determined by the solar constant which reaches up to 28500 W/m². All exposed items as antennae and solar arrays will be tailored to these conditions, and the spacecraft body will remain protected behind a sunshield, housing also the apertures of the Remote Sensing instruments.

The sunshield was the subject of two Technology Demonstration Activities (TDA) awarded by ESA to Astrium and Thales Alenia Space, aimed at designing the sunshield, developing the manufacturing technologies and the test method to verify the performances under simulated flight conditions at 0.22 AU. The activities were completed in late 2007.

At the end of 2007 ESA selected Astrium as the system contractor responsible for the mission; a Phase B2 (definition phase) which is about to start, will mature the

design and the technologies. TAS will be involved in the areas of power, transmission and thermal subsystems.

This paper describes the Thales Alenia Space spacecraft design concept and in particular the heat shield design, test, correlation and the extrapolation of test results to flight conditions.

INTRODUCTION

Main design drivers for Solar Orbiter mission and their impact on thermal design are:

- Cost and schedule: emphasize recurring units and reuse the specific developments of Bepi Colombo, especially on Solar Array and High Gain Antenna, need to adapt and qualify them for new thermal environment
- Perihelion at 0.22 AU: thermal fluxes up to 28500 W/m², high irradiances, UV ageing and solar disturbance torques, with constraints on configuration and thermal design solutions
- Aphelion at 1.5 AU: large variation of solar constant from 0.5 to 22 Earth value, need to minimize heater power and reduce heat rejection from radiators in cold case
- Very large data transmission capability required, due to large variation of distance Earth – spacecraft, large dissipation of internal systems when close to sun.
- Numerous scientific instruments with severe thermal control requirements, such as sensors at -50°C in Remote Sensing Instruments, need for dedicated thermal control for instruments.

Accounting for these constraints, TAS proposed a spacecraft with these main features:

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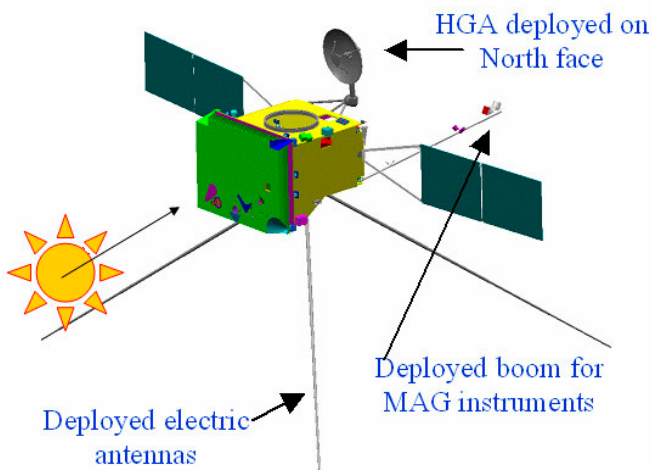


Figure 1: Solar orbiter design (1)

- Compact configuration
- Heat shield on the face exposed to sun, containing feed through and doors of Remote Sensing Instruments. Feed through are used to protect the instruments from the hot shield, while optical baffles are part of the instrument.
- Solar arrays with different ratio cells / OSR on the two faces, for optimal use in cruise and close to sun. The face with 100% cells is used in the first cruise period, then approaching the sun the solar arrays expose the side with 25% cells, and increase the rotation up to 65 deg to keep the cell temperature below 250°C.
- High gain antenna is normally deployed in cruise phase and science phases, it can be folded again in shadow of the S/C, still operating with Earth in anti-sun half space

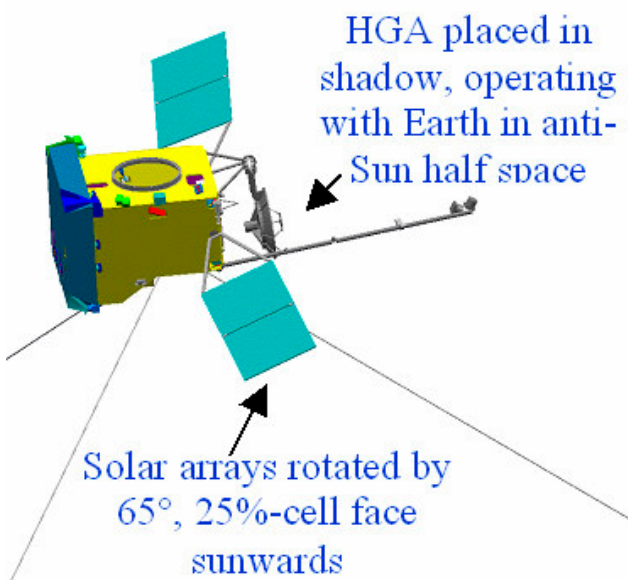


Figure 2: Solar orbiter solar arrays and HGA

- Thermal control: service units are mounted mainly on anti-sun face, used as main radiator. Most P/L are mounted on South face, with several radiators on south, east, west faces, at different temperatures, from -60 °C to +40 °C. Variable conductance Heat Pipes are used for temperature stabilization. Some are allowed to freeze to cut cooling in cruise cold phase.

HEAT SHIELD DESIGN

Design drivers for the HS have been:

1. Ensure adequate structural performance in terms of stiffness and strength without exceeding in mass
2. Ensure adequate thermal performance, i.e. very low heat load into the S/C (< 100 W at 0.22 AU)
3. Provide adequate cut outs and interfaces for instrument baffles
4. Provide an easy instrument accommodation
5. Be simple and modular
6. Be testable separately from S/C body

A simple high temperature MLI lying on the sun face of the S/C body (called sun panel) was not suitable, due to the very high efficiency required to keep the overall flux into the spacecraft small, which would require an enormous number of layers and consequently mass.

The selected design features some highly reflecting layers in the IR (high temperature barriers) creating gaps used to reflect to space the radiant heat entering from the first sunlit layer (called front shield). The sun panel is part of the HS module, it is larger than the S/C body to protect it when pointing off-sun (maximum 5°) and its extension anti-sun face is used as radiator to further reduce the heat load into the S/C body.

A low temperature MLI is used on both sides of the sun panel. Brackets are used to support the layers. Feed through are mounted on the sun panel with stand offs. A light block is necessary in case the front shield is of semi-transparent material.

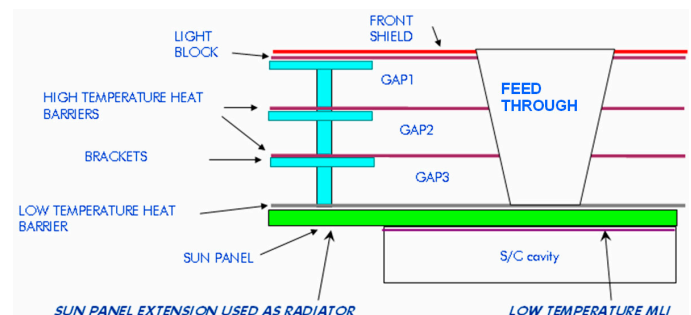


Figure 3: Heat Shield concept

Materials are: a black carbon-carbon fabric for the front shield, polished Nickel sheets for the light block and the high temperature barriers, stainless steel for the brackets and baffles, standard MLI on the sun panel.

They were chosen with the support of screening tests made on samples, consisting of thermo-optical properties at ambient temperature, surface electrical resistance, outgassing, mechanical test, scanning electron microscopy. Tests were made before and after endurance test at high temperature.

This design was the result of trade offs, in particular:

Flexible and rigid layers: flexible was selected as it decreases the manufacturing complexity, combined with the isostatic matrix of brackets it guarantees low level of distortion. Dynamic displacements were used to evaluate minimum looseness (> 5 mm) of flexible layers versus support structure (between two consecutive attachment points) necessary to avoid ripping them during launch.

Black or white front shield: candidates were black fabric or black paint on metal sheet, versus white fabric as Nextel or white paint on metal sheet. Black carbon fabric was selected for its electrical conductivity, poor in case of glass or quartz fibre fabrics, and for its stability.

Reflective layers material: candidates were Titanium, steel, Nickel, either polished or with deposited IR reflective layer. Nickel was selected for its mechanical properties, in particular high IR reflectance. A light block of Nickel was used, being the front shield fabric slightly transparent, and to reduce the emittance side S/C, it was separated from the front shield with a net of glass fibre.

Mechanical design incorporated isostatic brackets; they provide low distortions of the sun panel, flexibility versus instrument accommodation.

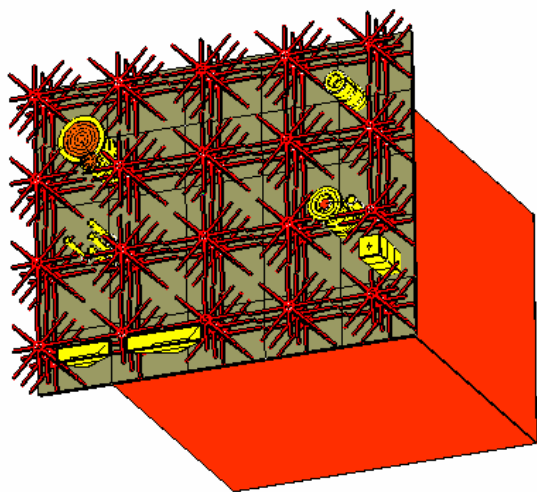


Figure 4: Heat Shield thermal mathematical model

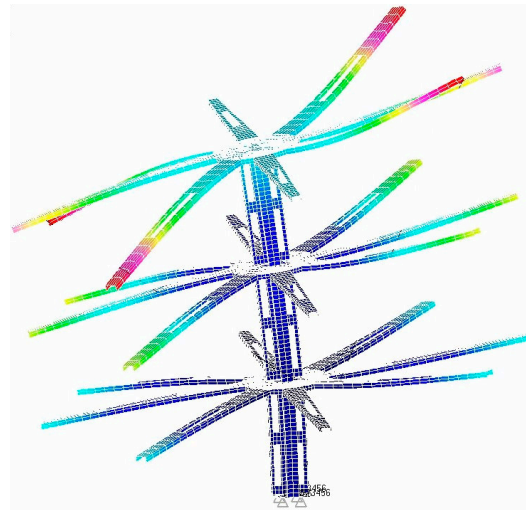


Figure 5: Heat Shield structural mathematical model

Lumped parameter models with ALTAN/ESARAD and ESATAN were extensively used for thermal design, FEM models for mechanical design.

From simulations the expected temperatures at 0.22 AU are 600-610 °C for the front shield, 490-515 °C for the light block, 210-320 °C for the hottest barrier, 60-170 °C for the second barrier, 10-80 °C for the MLI on sun panel, 30-70 °C for sun panel, and the total heat into the S/C varies between 10 and 20 W for a S/C at 40 °C.

It was also understood that the main source of heat into the sun-panel and S/C was the conduction from the feed throughs at the mechanical interfaces, followed by the radiative heat transfer among the layers, and finally the conduction due to the brackets. All such contributions are affected by considerable uncertainties: layers will not remain parallel, their geometry is unpredictable, in particular at high temperature when they expand, their optical properties are not known precisely at high temperature, the conduction for brackets and baffles depends on contact conductance among their parts and with the sun panel.

These uncertainties justify the need of a thermal balance test to verify the HS thermal performances in a simulated environment at 0.22 AU.

THERMAL BALANCE TEST SET-UP

A breadboard was manufactured, with the following characteristics:

- Full Scale (2.17 x 1.75 m)
- With two dummy feed through (EUS and SWA HIS) in a conservative location
- With a S/C simulator made of honeycomb panels, and with representative thermal I/F between the HS and S/C