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A thermal control surface for the Solar Orbiter

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ABSTRACT

A high-absorptivity/high-emissivity (flat absorber) bone char-based thermal control surface known as SolarBlack has been developed for use on rigid and flexible metallic substrates, including titanium, aluminium, copper, stainless steel, Inconel and magnesium alloys. This work describes the thermo-optical properties, stability, and qualification of this surface for use on the European Space Agency's Solar Orbiter mission. SolarBlack is deposited using a proprietry coating technique known as CoBlast and currently stands as the baseline coating for the spacecraft's front surface heat-shield, which is composed of 50 μm titanium foils (1.3 × 0.3 m) that have been constructed to cover the 3.1 × 2.4 m^2 shield. The heat shield makes use of the material's highly stable ratio of solar absorptance to near-normal thermal emissivity (α_s/ε_N) as well as its low electrical resistivity to regulate both temperature and electrostatic dissipation in service. SolarBlack also currently stands as the baseline surface for the High-gain and Medium-gain antennae as well as a number of other components on the spacecraft. The thermo-optical stability of SolarBlack was determined using the STAR Facility space environment simulator in ESTEC., Material characterisation was carried out using: SEM, UV/Vis/NIR spectrometry, and IR emissometry. The coating performance was verified on the Structural Thermal Model using ESA's Large Space Simulator.

1. Introduction

The Solar Orbiter (SolO) is an M-class mission, currently under collaborative development by the European Space Agency (ESA) and the National Aeronautic and Space Administration (NASA) [1–4]. The mission's primary launch window is set for October of 2018 and aims to answer several questions about our sun and how it produces the heliosphere via in-situ measurements in the inner solar system in conjunction with remote-sensing observation of the Sun and the Corona [4]. The SolO mission summary is outlined in Table 1. The mission had originally been intended to reach perihelion of 0.22 AU [4], however this was increased due to growing concerns surrounding the thermal challenges posed by the mission. Depending on the mission launch date, SolO (depicted in Fig. 1) is now expected to achieve a perihelion of 0.28 AU [3] following multiple Gravitational Assist Manoeuvres (GAMs) at Earth and Venus. SolO is due to launch alongside its American counterpart, the Solar Probe Plus (SPP or SP+) (0.06 AU, expected), in 2018, with both spacecraft expected to surpass Helios-2 (0.29 AU [5]) in terms of proximity to the Sun.

Though the hostile thermal environment of the mission is with precedent, as evidenced by the Helios mission, new technologies were required to ensure Solar Orbiter's survival over far longer periods under such conditions. SolO will never reach see the same Solar Flux to be encountered

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Table 1
Solar Orbiter mission summary [3].

Top-level Science Questions	• How and where do the solar wind plasma and magnetic field originate in the corona? • How do solar transients drive heliospheric variability? • How do solar eruptions produce energetic particle radiation that fills the heliosphere? • How does the solar dynamo work and drive connections between the Sun and the heliosphere?

Science Payload	• Heliosperic In-Situ Instruments:
	  • Solar Wind Analyser (SWA)
	  • Energetic Particle Detector (EPD)
	  • Magnetometer (MAG)
	  • Radio and Plasma Wave analyser (RPW)
	• Solar Remote-Sensing Instruments:
	  • Polarimetric and Helioseismic Imager (PHI)
	  • EUV full-sun and high-resolution Imager (EUI)
	  • EUV spectral Imager (SPICE)
	  • X-ray spectrometer/telescope (STIX)
	  • Coronagraph (METIS)
	  • Heliospheric Imager (SoloHI)

Mission Profile	• Launch on NASA-provided Evolved Expendable Launch Vehicle (Ariane 5 as back-up) • Interplanetary cruise with chemical propulsion and gravity assists at Earth and Venus • Venus resonance orbits with multiple gravity assists to increase inclination
Spacecraft	3-axis stabilized platform, heat shield, two adjustable, 2-sided solar arrays, dimensions: 2.5 × 3.0 × 2.5 m^3 (launch configuration)
Orientation	Sun-pointing
Telemetry Band	Dual X-band
Data Downlink	150 kbps (at 1 AU S/C-Earth distance)
Launch Date	October 2018
Nominal Duration	7 years (incl. cruise phase)
Extended Duration	3 years
Post-Ops & Archiving	2 years
Ground Station	Malargue (Argentina), 35- m antenna
Programmatic	ESA is responsible for the Solar Orbiter spacecraft, transfer to nominal science orbit, and mission operations. • NASA is responsible for launch vehicle provision and launch operations. • Science payload provided by ESA member states and NASA.

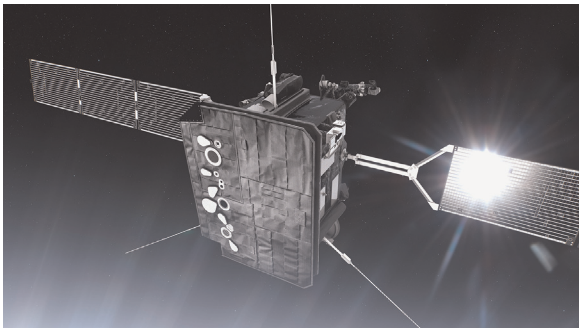

Fig. 1. Artist's render of the Solar Orbiter spacecraft, with detail of the heatshield FS. Image courtesy of the European Space Agency.

by SP+, however it should be noted that SolO's true innovation is not its proximity to the sun, but rather its ability to carry out indirect *in-situ* and direct *remote sensing* measurements of the sun at a closer distance and higher inclination than ever before [3]. To achieve this, the craft is protected by a planar, multi-layered heat-shield developed by Thales Alenia Space (TAS) (Cannes, France/Turin, Italy). The design incorporates a Front Shield (FS) and several High Temperature Heat Barriers (HTHBs) [4] and includes multiple apertures for scientific instrumentation. The purpose of this work was to develop a Thermal Control Coating (TCC) for use on the SolO FS. Thermal control coatings make up part of a spacecraft's passive thermal control subsystem and rely solely on the thermo-optical properties of the deposited material for temperature regulation [6–8]. Through application of the Stefan Boltzmann law and the first law of thermodynamics, it can be shown [9,10] that the surface temperature of a small spherical body, isolated from the radiative flux associated with planetary albedo, and with known thermo-optical properties, may be determined according to Eq. (1):

$$T_{s/c} = \sqrt[4]{\frac{S\ \alpha_s A_s}{\sigma\ \varepsilon_N A_R}} \propto \left(\frac{\alpha_s}{\varepsilon_N}\right)^{1/4} \tag{1}$$

where: $T_{s/c}$ is equilibrium temperature of a spherical body or surface at normal orientation to some radiation source, S is the solar constant or irradiance from said radiation source, σ is the Stefan-Boltzmann constant ($5.67 \times 10-8\ \mathrm{W\,m^{-2}K^{-4}}$), α_s is the solar absorptance of the thermal control surface, ε_N is the normal emittance of the thermal control surface, A_R is the area of the radiating/total surface area of the spacecraft, and A_S is the irradiated cross-sectional area of the thermal control surface. This equation can be used to approximate the equilibrium surface temperatures of real surfaces, with the primary implication being that the temperature of a surface at normal inclination to a radiation source is proportional to that material's α_s/ε_N ratio.

The use of multiple HTHBs in series provides a conventional thermal radiation shield, resulting in lateral heat rejection while reducing transverse transfer. Lateral heat rejection is further improved via the use of IR-reflective inner layers throughout the HTHBs. This heat shield design greatly reduces the thermo-optical requirements of the FS,